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NRL Report 6240

High-Temperature Properties of Cesium

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ABSTRACT

The experimental program at this Laboratory to measure various thermophysical properties of sodium, potassium, and cesium has been completed. Final reports on two of the alkali metals, sodium and potassium, have been published; and this is the final reporting on cesium. Experimental results are presented for the density and vapor pressure of the liquid and for various saturation and superheat properties of the vapor. A virial equation of state is advanced and is used thermodynamically to derive additional properties of the vapor. For example, enthalpy, entropy, specific volume, and specific heat are tabulated for some 1100 selected vapor states in the temperature range from 1250° to 2550° F and in the pressure range from 0.2 to 34.0 atm.

PROBLEM STATUS

This is the final report on the experimental work with cesium and the final report on this problem. All contracted measurements have been completed except for the surface tension of liquid potassium and cesium. This problem will be considered closed with the issuance of this report.

AUTHORIZATION

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HIGH-TEMPERATURE PROPERTIES OF CESIUM

INTRODUCTION

In the development of compact turboelectric systems for space vehicles, the National Aeronautics and Space Administration is sponsoring a property measurement program for the evaluation of several liquid metals as possible working fluids. As an integral part of this program, the U.S. Naval Research Laboratory contracted to measure several thermophysical properties of potassium to 2300° F, sodium to 2500° F, and cesium to 2300° F.

The saturated liquid properties which have been determined experimentally include density, vapor pressure, and specific heat (except for cesium). Saturated and superheated vapor properties, including specific volume, specific heat, enthalpy and entropy, have been derived from experimental pressure-volume-temperature (PVT) studies. All phases of this measurement program have been completed. The final properties of sodium (2) and potassium (1) have been published in companion reports; those of cesium are presented in this report.

EXPERIMENTAL MATERIALS AND METHODS COMMON TO ALL MEASUREMENTS

A number of materials, methods, and techniques were common to many of the experimental measurements. These include the container alloy, the high-pressure furnace system, the temperature measurement, and techniques for purifying and transferring the alkali metals. All are discussed at some length in the companion report on potassium (1), and only a short section to describe the purity of the cesium will be included in this report.

The cesium samples for the density determinations were distilled directly from a small glass still into the pycnometers. However, for the PVT determinations this procedure was impractical, and the metal was distilled and introduced into small columbium alloy capsules for subsequent transfer (1) into the PVT apparatus. Cesium introduced to the distillation retort for the density experiments, the PVT experiments, and one vapor-pressure experiment was a high-purity grade from MSA Research Corporation; and a typical spectrographic analysis of this cesium after one distillation at this Laboratory is presented in Table 1. Although the metal was distilled at low temperature under high vacuum, the still may have introduced some of the metal impurities, particularly silicon and sodium. A high-purity grade of cesium from Dow Chemical Company was used for one vapor-pressure experiment. The distilled sample of this cesium for analysis was lost, and the data reported in Table 1 are for an "as received" sample oxidized on Pyrex glass. It is very probable that silicon, aluminum, and sodium were introduced by reaction with glass under these conditions, and it is recognized that the analysis is unsatisfactory. However, since the volatile and non-volatile impurities in the MSA metal (and probably the Dow sample, too) are present in concentrations too low to produce a measurable vapor-pressure change, no additional analytical work was performed.

Table 1
Spectrographic Analyses of Cesium at NRL

| Metal Impurity | MSAR Sample (ppm) | Dow Chemical Sample (ppm) |
|----------------|-------------------|---------------------------|
| Rb | 500* | 10* |
| K | <10 | 1 |
| Na | 100* | 1000* |
| Li | Not detected | Not detected |
| Ca | 1 to 10 | 10 to 100 |
| Ba | Not detected | Not detected |
| Sr | Not detected | Not detected |
| Al | Not detected | 100 to 1000 |
| B | <1 | - |
| Si | 10 to 100 | 100 to 1000 |
| Mn | Not detected | <1 |
| Fe | Not detected | <1 |
| Mg | <1 | <1 |
| Cu | Not detected | 10 to 100 |

* Used standard samples for comparison; figures should be close to quantitative.

EXPERIMENTAL MEASUREMENTS

Pressure-Volume-Temperature Measurements of Cesium

Experimental Superheat Results - The PVT measurements in both the superheat and saturation regions were made with small closed chambers of columbium-1%zirconium using flexible diaphragms as null-detectors. This high-temperature apparatus and the methods employed are described in detail for potassium (1), and only the experimental results for cesium are included in this report.

The twelve PVT experiments for cesium (Table 2) covered a broad range in the superheat region with measured temperatures extending from 1305° to 2570°F and pressures from 1.1 to 33.2 atm. For each experimental point in this table, pressure and temperature were directly observed, and the specific volume was computed from the weight of cesium added to the chamber. The nominal volume of all chambers was 57 cc, and the weights of the cesium samples varied from 0.1173 g in experiment 30 to 2.4205 g in experiment 37.

To obtain the data at each equilibrium point in Table 2, multiple readings of temperature and pressure were made at 5 to 10 min intervals until successive readings showed a temperature drift of 0.07°F/min or less and a temperature difference across the chamber less than 2°F, and generally less than 1°F. In the measurement of pressures with the diaphragm device, the excellent reproducibility obtained during the other alkali metal measurements (1,2) continued for cesium. Measurements for each experiment (except

Table 2
Pressure-Volume-Temperature Measurements of
Cesium Superheat Region

| Temp. (°F) | Pressure (abs atm) | Specific Volume (cu ft/lb) | Temp. (°F) | Pressure (abs atm) | Specific Volume (cu ft/lb) |
|---------------|-----------------------|----------------------------------|---------------|-----------------------|----------------------------------|
| Experiment 27 | | | Experiment 30 | | |
| 1785.3 | 6.989 | 1.5321 | 1341.5 | 1.1489 | 8.0140 |
| 1953.8 | 7.697 | 1.5358 | 1460.8 | 1.2438 | 8.0266 |
| 2095.4 | 8.255 | 1.5390 | 1581.4 | 1.3384 | 8.0397 |
| 2201.6 | 8.679 | 1.5415 | 1712.7 | 1.4337 | 8.0543 |
| 2319.7 | 9.122 | 1.5443 | 1777.9 | 1.4772 | 8.0617 |
| 2425.8 | 9.528 | 1.5469 | 1801.5 | 1.5616 | 8.0760 |
| 2558.6 | 10.010 | 1.5502 | 1996.8 | 1.6275 | 8.0873 |
| 2520.4 | 9.873 | 1.5492 | 2094.8 | 1.6958 | 8.0991 |
| 2366.6 | 9.310 | 1.5454 | 2212.0 | 1.7752 | 8.1135 |
| 2262.5 | 8.914 | 1.5429 | 2314.1 | 1.8425 | 8.1263 |
| 2163.2 | 8.542 | 1.5406 | 2424.6 | 1.9155 | 8.1405 |
| 2044.8 | 8.050 | 1.5378 | 2571.4 | 2.0137 | 8.1597 |
| 1884.5 | 7.414 | 1.5342 | 2518.7 | 1.9786 | 8.1528 |
| 1826.2 | 7.167 | 1.5329 | 2465.0 | 1.9420 | 8.1457 |
| 1724.3 | 6.736 | 1.5307 | 2369.2 | 1.8827 | 8.1333 |
| 1741.1 | 6.808 | 1.5311 | 2257.5 | 1.8069 | 8.1192 |
| Experiment 28 | | | 2139.4 | 1.7288 | 8.1045 |
| 1649.0 | 4.849 | 2.0879 | 2029.2 | 1.6527 | 8.0912 |
| 1703.2 | 5.024 | 2.0894 | 1948.5 | 1.5970 | 8.0815 |
| 1822.0 | 5.378 | 2.0929 | 1847.8 | 1.5262 | 8.0697 |
| 1612.7 | 4.745 | 2.0868 | 1649.8 | 1.3853 | 8.0473 |
| 1737.2 | 5.138 | 2.0904 | 1515.0 | 1.2853 | 8.0325 |
| 1854.8 | 5.480 | 2.0939 | 1391.1 | 1.1901 | 8.0192 |
| 1978.8 | 5.862 | 2.0977 | 1305.0 | 1.1227 | 8.0103 |
| 2081.0 | 6.145 | 2.1009 | Experiment 31 | | |
| 2178.4 | 6.419 | 2.1040 | 1909.1 | 9.615 | 1.1606 |
| 2275.0 | 6.697 | 2.1071 | 2037.4 | 10.327 | 1.1628 |
| 2379.1 | 6.971 | 2.1105 | 2143.7 | 10.881 | 1.1646 |
| 2485.2 | 7.258 | 2.1141 | 2236.7 | 11.375 | 1.1663 |
| 2565.6 | 7.488 | 2.1169 | 2363.0 | 12.033 | 1.1686 |
| 2523.2 | 7.370 | 2.1154 | 2462.0 | 12.515 | 1.1704 |
| 2441.6 | 7.143 | 2.1126 | 2568.2 | 13.044 | 1.1724 |
| 2329.0 | 6.848 | 2.1089 | 2518.6 | 12.800 | 1.1715 |
| 2221.4 | 6.552 | 2.1054 | 2415.6 | 12.290 | 1.1695 |
| 2116.9 | 6.252 | 2.1020 | 2305.0 | 11.722 | 1.1675 |
| 2038.2 | 6.033 | 2.0995 | 2186.5 | 11.115 | 1.1654 |
| 1919.5 | 5.699 | 2.0959 | 2081.2 | 10.558 | 1.1635 |
| 1766.5 | 5.223 | 2.0913 | 1959.5 | 9.890 | 1.1614 |
| 1624.3 | 4.793 | 2.0871 | 1827.0 | 9.158 | 1.1592 |
| 1647.5 | 4.859 | 2.0878 | | | |

(Table continues)

Table 2 (cont'd)
Pressure-Volume-Temperature Measurements of
Cesium Superheat Region

| Temp. (°F) | Pressure (abs atm) | Specific Volume (cu ft/lb) | Temp. (°F) | Pressure (abs atm) | Specific Volume (cu ft/lb) |
|---------------|-----------------------|----------------------------------|---------------|-----------------------|----------------------------------|
| Experiment 32 | | | Experiment 37 | | |
| 1846.9 | 9.367 | 1.1468 | 2405.0 | 31.319 | .38763 |
| 1944.1 | 9.909 | 1.1484 | 2512.7 | 33.112 | .38830 |
| 2058.5 | 10.549 | 1.1504 | 2519.7 | 33.223 | .38835 |
| 2175.7 | 11.176 | 1.1524 | 2487.5 | 32.688 | .38815 |
| 2291.4 | 11.781 | 1.1545 | 2445.9 | 31.988 | .38789 |
| 2396.2 | 12.331 | 1.1564 | 2355.1 | 30.470 | .38733 |
| 2497.5 | 12.866 | 1.1582 | 2315.1 | 29.779 | .38709 |
| 2558.8 | 13.169 | 1.1594 | Experiment 38 | | |
| 2452.0 | 12.613 | 1.1574 | 1578.9 | 3.3677 | 3.0146 |
| 2363.8 | 12.182 | 1.1558 | 1684.9 | 3.560 | 3.0190 |
| 2258.3 | 11.523 | 1.1535 | 1801.0 | 3.805 | 3.0239 |
| 2140.1 | 10.993 | 1.1518 | 1921.5 | 4.067 | 3.0292 |
| 1973.9 | 10.082 | 1.1489 | 2015.7 | 4.237 | 3.0334 |
| 1894.9 | 9.643 | 1.1476 | 2136.8 | 4.462 | 3.0389 |
| 1830.5 | 9.283 | 1.1465 | 2230.5 | 4.649 | 3.0432 |
| Experiment 34 | | | 2348.2 | 4.871 | 3.0488 |
| 2068.0 | 15.241 | .75273 | 2437.7 | 5.041 | 3.0531 |
| 2174.2 | 16.156 | .75394 | 2523.8 | 5.191 | 3.0574 |
| 2184.2 | 16.245 | .75405 | 2479.4 | 5.116 | 3.0552 |
| 2294.0 | 17.171 | .75333 | 2314.0 | 4.816 | 3.0472 |
| 2387.8 | 17.938 | .75644 | 2193.8 | 4.579 | 3.0415 |
| 2483.7 | 18.723 | .75760 | 2076.7 | 4.359 | 3.0361 |
| 2543.1 | 19.212 | .75833 | 1970.3 | 4.162 | 3.0314 |
| 2516.5 | 18.990 | .75800 | 1864.1 | 3.958 | 3.0267 |
| 2437.0 | 18.360 | .75703 | 1777.8 | 3.768 | 3.0230 |
| 2347.6 | 17.622 | .75596 | 1640.8 | 3.488 | 3.0172 |
| 2247.9 | 16.797 | .75479 | 1521.8 | 3.2316 | 3.0123 |
| 2119.4 | 15.700 | .75331 | Experiment 39 | | |
| 2024.9 | 14.880 | .75225 | 2183.7 | 21.758 | .52803 |
| Experiment 35 | | | 2320.2 | 23.438 | .52915 |
| 2126.4 | 17.659 | .65739 | 2423.6 | 24.691 | .53001 |
| 2223.6 | 18.612 | .65836 | 2540.7 | 26.064 | .53101 |
| 2329.0 | 19.636 | .65944 | 2487.0 | 25.440 | .53055 |
| 2492.6 | 21.162 | .66115 | 2379.4 | 24.173 | .52964 |
| 2447.0 | 20.727 | .66067 | 2260.0 | 22.717 | .52865 |
| 2401.2 | 20.307 | .66019 | 2222.7 | 22.257 | .52835 |
| 2290.3 | 19.263 | .65904 | 2149.9 | 21.356 | .52776 |
| 2172.1 | 18.102 | .65784 | Experiment 40 | | |
| 2061.6 | 17.013 | .65675 | 2355.6 | 27.309 | .44574 |
| Experiment 36 | | | 2469.1 | 28.975 | .44654 |
| 2300.6 | 26.112 | .45493 | 2527.9 | 29.820 | .44696 |
| 2397.6 | 27.503 | .45563 | 2414.6 | 28.214 | .44615 |
| | | | 2309.9 | 26.695 | .44542 |
| | | | 2263.9 | 25.998 | .44510 |
| | | | 2228.8 | 25.491 | .44486 |

experiment 36) were made over a minimum of one full cycle from the normal boiling point to about 2550°F, and equilibrium pressures were generally reproduced in the superheat region to better than ± 0.1 psi (0.0068 atm) before, during, and after cycling.

Specific Volumes of Saturated Vapor - Specific volumes of several saturated vapor states (Table 3) were observed over the temperature range from 1251° to 2269°F. The measurements were made in the course of the PVT studies, and each point represents an intersection of the saturated and superheated vapor curves for one of the twelve PVT experiments. In the previous experiments with potassium (1) and sodium (2), observed pressures in the temperature region near the intersection of the saturated and superheat curves were always abnormally low. This phenomenon was also observed for cesium and was particularly noticeable in the low-weight, low-pressure experiments. The several factors which may contribute to this lowering phenomenon include the existence of dual states, elevation of the boiling point by nonvolatile impurities, and the retention of condensed alkali metal on the walls of the chamber by adsorption and capillarity effects. These factors are discussed in detail in the potassium report (1).

Table 3
Specific Volume of Saturated Cesium Vapor

| Experiment Number | Temperature (°F) | Specific Volume (cu ft/lb) |
|-------------------|------------------|----------------------------|
| 30 | 1250.9 | 8.005 |
| 38 | 1484.3 | 3.011 |
| 28 | 1588.2 | 2.086 |
| 27 | 1687.3 | 1.530 |
| 31 | 1784.8 | 1.159 |
| 32 | 1789.9 | 1.146 |
| 34 | 1955.8 | 0.7515 |
| 35 | 2014.2 | 0.6561 |
| 39 | 2114.6 | 0.5275 |
| 36 | 2187.0 | 0.4542 |
| 40 | 2197.4 | 0.4448 |
| 37 | 2269.4 | 0.3869 |

The saturated specific volume for each PVT experiment was obtained by a short extrapolation of the superheated vapor curve to the true saturation curve as defined by the vapor-pressure equation (Eq. (1)). Although this extrapolation procedure tended to minimize any error in the saturated specific volume resulting from the depression phenomenon, it is believed that specific volumes obtained from the virial equation (Eq. (13)) and the vapor-pressure equation (Eq. (1)) will be of higher reliability than those observed at the intersection points (Table 3). Even so, corresponding values computed from the virial equation show an average deviation of only $\pm 0.43\%$ from the observed values.

Discussion of Superheat Results - The sources and magnitudes of errors in the PVT measurements are discussed in detail for potassium (1). Many of these were common to the PVT studies of the three alkali metals, and only those which are specific to the cesium work are included here.

Although the procedures developed with potassium and sodium for degassing and closing of null-point apparatuses were very effective, the possibility of inadvertently trapping gas in a chamber still existed. Each cesium apparatus was checked for gas at the

conclusion of an experiment by opening the chamber to an evacuated manometer. Gas pressures as low as 0.01 psi were detectable in this manner, and no gas was detected in any of the twelve cesium chambers.

In previous studies with sodium and potassium, two apparatuses (57 cc and 113 cc) with significantly different surface-to-volume ratios were used for each metal. A comparison for each metal of the compressibility factors measured with the two apparatuses provided evidence that adsorption of the alkali metal on the container surfaces was insignificant. Hence, for cesium the standard 57-cc apparatus was used for all experiments.

The possible significance of any thermal ionization in potassium and sodium vapors is discussed in the companion reports (1,2). It was shown that the degree of ionization to be expected in metal vapor may be obtained from its ionization potential (3). A maximum figure of 10^{-6} was estimated for cesium vapor at 2500°F ; this leads to the conclusion that the degree of ionization is several magnitudes too low to produce a measurable increase in pressure.

The results of PVT measurements are generally reported in the form of compressibility factors since these, in one form or another, are employed directly in the thermodynamic reduction of data. It is therefore desirable to express experimental error in terms of these factors. If we take into account all known uncertainties, the percent probable error in the observed compressibility factor ranges from ± 0.25 to ± 0.28 .

Experimental Saturation Pressures - Saturation pressures of cesium from 1.00 atm at 1236°F to 33.53 atm at 2346°F were measured with two separate PVT apparatuses using in each a large excess of the alkali metal. Redistilled cesium metal from two sources (MSA Research Corporation and Dow Chemical Company) was used for these determinations, and the results are presented in the "Vapor-Pressure Experiments" section of Table 4. Pressures up to 24.7 atm were also measured in the course of twelve PVT experiments and are presented in the second section of the same table. It has been shown that the saturation pressures observed for each experiment near the intersection of the saturation and superheat curves were below corresponding values on the true saturation curve. This lowering of the vapor pressure can be satisfactorily explained (1), and observed pressures in these regions are not included in the table.

The vapor-pressure data in Table 4 are presented graphically in Fig. 1. It is evident from a larger scale plot of this figure that $\log p$ versus $1/T$ for cesium is not linear. The data can be effectively fitted for the full temperature range (normal boiling point to 2346°F) with one three-term equation of the Kirchhoff type. Three vapor-pressure equations

$$\log p = 5.87303 - \frac{7040.7}{T} - 0.53290 \log T \quad (1)$$

$$\log p = 5.87275 - \frac{7039.4}{T} - 0.53290 \log T \quad (2)$$

$$\log p = 5.79014 - \frac{7020.7}{T} - 0.51090 \log T \quad (3)$$

for cesium were obtained by least-squares (computer) treatments of the data. Equation (1) was derived from a treatment using all the observed vapor pressures above the normal boiling point, Eq. (2) was derived from the data of the two vapor-pressure experiments in the first section of Table 4, and Eq. (3) was derived from twenty points selected at equal intervals of $1/T$ from a smoothed plot of $\log p$ versus $1/T$ for all the data. The average deviation of all the observed vapor pressures in Table 4 from corresponding values computed with any one of the three equations is $\pm 0.35\%$. The three equations are, therefore, equivalent; and the thermodynamic quantities in this report are arbitrarily based on Eq. (1). The normal boiling point as obtained from Eqs. (1) and (3) is 1236.0°F (668.9°C) and from Eq. (2) is 1235.8°F (668.8°C).

Table 4
Saturated Vapor Pressures of Cesium

| Temp. (°F) | Pressure (abs atm) | Temp. (°F) | Pressure (abs atm) | Temp. (°F) | Pressure (abs atm) | Temp. (°F) | Pressure (abs atm) |
|-----------------------------------|-----------------------|---------------|-----------------------|--------------------------------------|-----------------------|---------------|-----------------------|
| Vapor-Pressure Experiments | | | | Vapor Pressures from PVT Experiments | | | |
| (MSA Research Corporation Sample) | | | | 1277.0 | 1.2421 | 1284.0 | 1.2672 |
| | | | | 1440.6 | 2.6328 | 1449.7 | 2.7180 |
| | | | | | | 1332.1 | 1.6123 |
| 1238.0 | 1.0169 | 2276.1 | 29.384 | 1509.5 | 3.465 | 1197.4 | 0.8110 |
| 1346.6 | 1.7426 | 2218.7 | 26.195 | 1377.5 | 1.9968 | 1342.0 | 1.7030 |
| 1428.4 | 2.5054 | 2169.5 | 23.632 | 1322.8 | 1.5498 | 1480.4 | 3.1044 |
| 1535.0 | 3.829 | 2140.1 | 22.178 | 1229.6 | 0.9662 | 1619.1 | 5.234 |
| 1618.3 | 5.179 | 2067.7 | 18.833 | 1214.5 | 0.8794 | 1546.9 | 4.026 |
| 1699.8 | 6.825 | 2027.3 | 17.108 | 1361.1 | 1.8492 | 1420.4 | 2.4223 |
| 1785.9 | 8.918 | 1943.3 | 13.885 | 1495.8 | 3.2740 | 1312.5 | 1.4970 |
| 1885.2 | 11.357 | 1857.1 | 11.013 | 1391.8 | 2.1516 | 1264.0 | 1.1811 |
| 1977.8 | 15.108 | 1759.2 | 8.263 | 1510.7 | 3.503 | 1404.9 | 2.2671 |
| 2100.8 | 20.264 | 1677.6 | 6.354 | 1606.9 | 5.000 | 1547.7 | 4.045 |
| 2183.5 | 24.276 | 1588.6 | 4.672 | 1447.6 | 2.7089 | 1689.7 | 6.636 |
| 2243.1 | 27.471 | 1491.5 | 3.2325 | 1340.5 | 1.6879 | 1262.4 | 1.1450 |
| 2291.0 | 30.241 | 1440.0 | 2.6191 | 1251.9 | 1.0936 | 1387.9 | 2.0987 |
| 2345.5 | 33.530 | 1318.6 | 1.5122 | 1403.3 | 2.2469 | 1560.5 | 4.226 |
| 2316.6 | 31.738 | 1214.5 | 0.6849 | 1553.9 | 4.135 | 1685.6 | 6.532 |
| (Dow Chemical Company Sample) | | | | 1688.5 | 6.607 | 1827.6 | 10.072 |
| | | | | 1822.1 | 9.998 | 1747.5 | 7.947 |
| | | | | 1974.5 | 15.034 | 1642.6 | 5.654 |
| | | | | 1285.4 | 1.2836 | 1489.5 | 3.1996 |
| | | | | 1436.1 | 2.5700 | 1363.5 | 1.8702 |
| | | | | 1573.6 | 4.415 | 1532.3 | 3.786 |
| | | | | 1708.0 | 7.006 | 1930.4 | 13.395 |
| 1353.4 | 1.7991 | 2247.2 | 27.730 | 1852.8 | 10.844 | 1755.8 | 8.158 |
| 1505.6 | 3.438 | 2177.2 | 24.015 | 1985.7 | 15.495 | 1474.3 | 3.0178 |
| 1554.4 | 5.905 | 2130.5 | 21.720 | 2131.9 | 21.796 | 1281.9 | 1.2674 |
| 1806.6 | 9.543 | 2034.2 | 17.392 | 2194.4 | 24.725 | 1333.3 | 1.6746 |
| 1948.3 | 14.068 | 1888.4 | 12.039 | 2080.8 | 19.346 | 1465.2 | 2.9205 |
| 2091.8 | 19.909 | 1761.6 | 8.396 | 1923.7 | 13.164 | 1480.8 | 3.1151 |
| 2201.0 | 25.215 | 1601.8 | 4.925 | 1776.1 | 8.683 | 1373.5 | 1.9546 |
| 2322.0 | 32.067 | 1431.5 | 2.5592 | 1651.3 | 5.821 | 1252.8 | 1.0887 |
| 2287.9 | 30.071 | 1245.5 | 1.0629 | 1514.5 | 3.533 | | |

The current vapor-pressure results are compared to those of three previous investigators in Fig. 2. Vapor pressures of cesium above the normal boiling point have been observed by Achener (4) over the temperature range from 893° to 1600°F, by Tepper et al. (5) over the temperature range from 852° to 1941°F, and by Bonilla et al. (6) over the temperature range from 754° to 1700°F. In Fig. 2 the NRL results have been arbitrarily taken as standard, and the percent deviation of the vapor pressure of each other investigator is plotted as a function of temperature. It is noteworthy that all data show good agreement, the deviation between any two sets being generally accounted for by the combined experimental errors.

A third-law calculation of the heat of vaporization to the monomer (at a temperature of absolute zero) can be made from saturation pressure data with Eq. (4) if other thermal quantities are known.

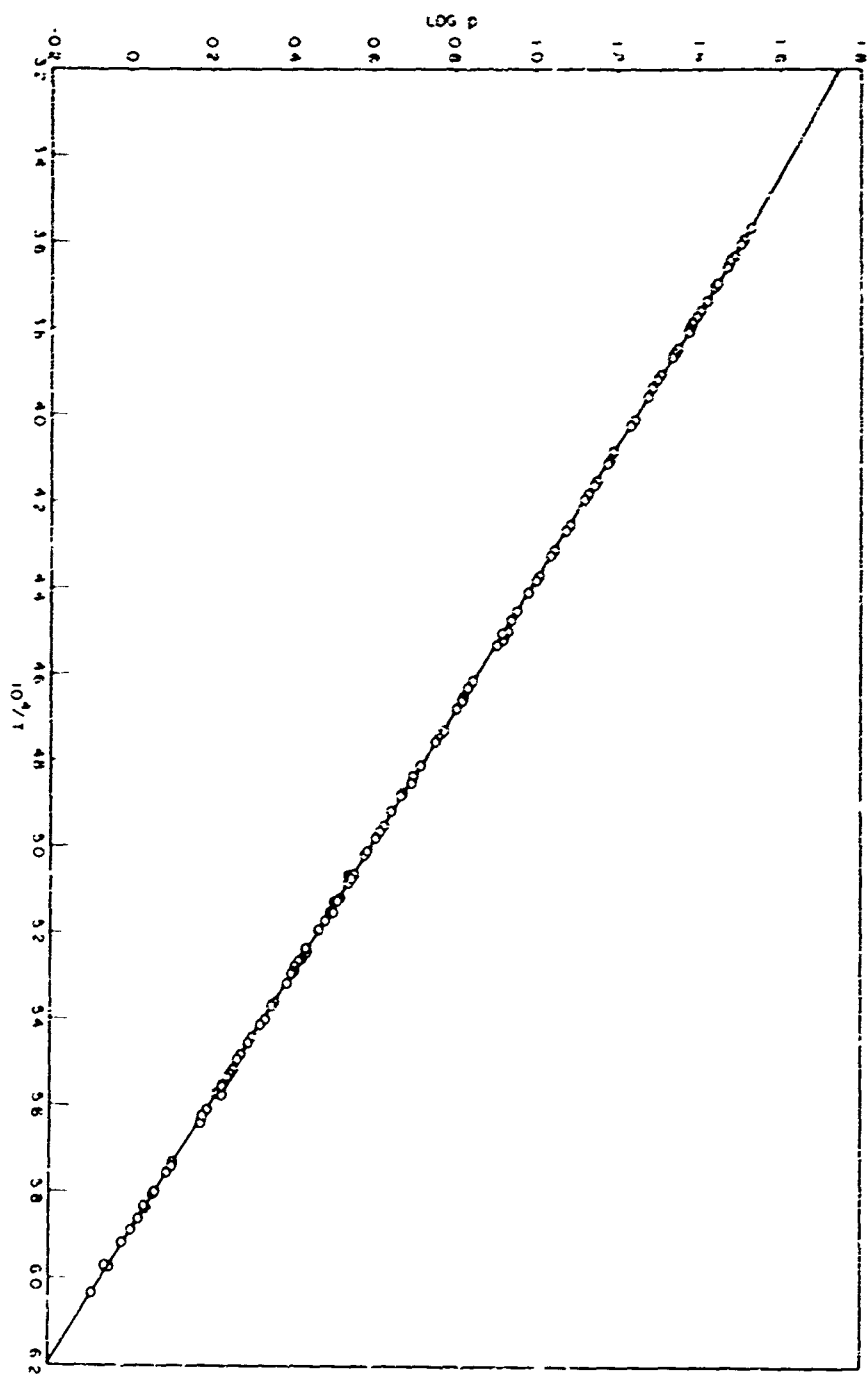


Fig. 1 - Vapor pressure of cesium as a function of the reciprocal absolute temperature

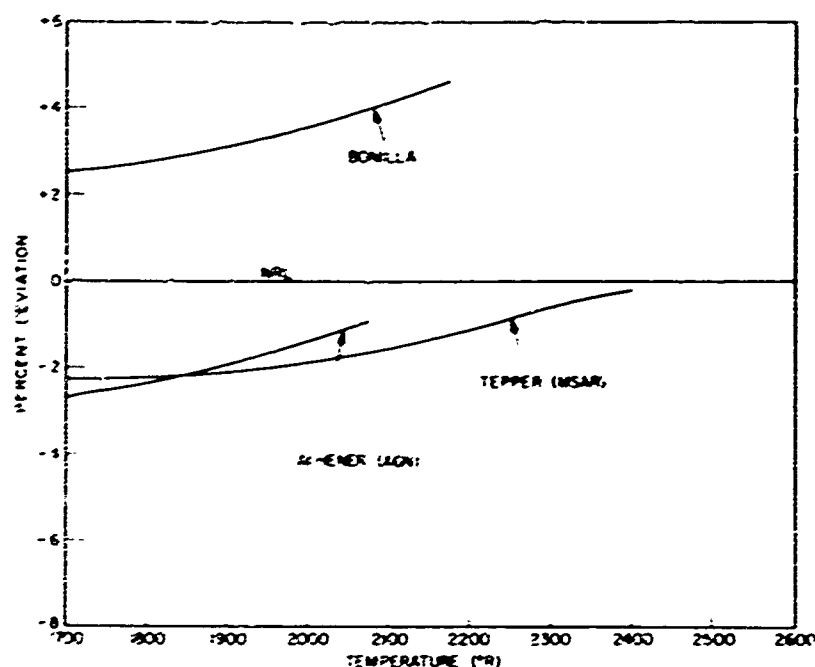


Fig. 2 - Comparison of vapor-pressure data of cesium by several investigators using the NRL data as standard

$$(\Delta h_g^o)_t = -\frac{RT}{M_1} \left(\frac{2B}{\tilde{V}} - \frac{3C}{2\tilde{V}^2} - \frac{4D}{3\tilde{V}^3} - \frac{5E}{4\tilde{V}^4} + \ln p_s - \ln \frac{p_s \tilde{V}}{RT} \right) - T \left[\left(\frac{f^o - h_g^o}{T} \right) \right]_t \quad (4)$$

The virial coefficients for cesium, which appear in the imperfection term, are developed later in this report. The free-energy functions for monomeric cesium gas can be obtained from Evans et al. (7), and corresponding functions for the liquid may be derived from heat-capacity results. Three recent measurements for cesium were found in the literature and pertinent data related to each are summarized in Table 5. It will be noted that there is significant disagreement in the magnitude of the specific heat and the shape of its temperature curve. Since there was no apparent reason to select one set of specific heat data over another, it was decided to base the selection of both c_p^l and $(\Delta h_g^o)_t$ on a third-law analysis of the NRL vapor-pressure results. Normally a third-law analysis is used to check the internal consistency of vapor-pressure measurements. In this case, the analysis was used to obtain the most consistent values for the specific heat of the liquid and the vaporization constant.

Table 5
Summary of Heat Capacity Measurements of Liquid Cesium

| Investigator and Reference | Temperature Range (°F) | Heat Capacity Equation |
|----------------------------|------------------------|---|
| Achener (4) | 152 to 1656 | $c_p^l = 0.08543 - 9.605 \times 10^{-5}t + 5.985 \times 10^{-6}t^2$ |
| Tepper (5) | 620 to 1770 | $c_p^l = 0.0545$ |
| Lemmon (8) | 570 to 2100 | $c_p^l = 0.0660$ |

In two preliminary analyses, the value of (ΔH_v°) , was computed over the temperature range from 1215° to 2346°F from the vapor-pressure data in Table 4, using in one case a constant liquid heat capacity of 0.0545 and in the other 0.0600 Btu/lb-°F. It will be noted that these are the heat capacities reported by Tepper et al. (5) and Lemmon et al. (8), respectively. (Thermal data at lower temperatures are also required in these analyses, and the data selected are presented in the section entitled "Enthalpy and Entropy of Liquid Cesium.") When the vaporization quantities were plotted against temperature, those computed with a liquid specific-heat value of 0.0600 exhibited a negative slope, and those computed with a value of 0.0545 exhibited a positive slope. It followed that a constant value, intermediate between those chosen, would lead to a nearly constant value of (ΔH_v°) , for all saturation results. By a trial and error procedure this value for the specific heat of the liquid was found to be 0.5683 Btu/lb-°F. The vaporization heats (converted to cgs units) computed from this specific-heat value are plotted as a function of temperature in Fig. 3. The value of (ΔH_v°) , obtained by this procedure is 18.62 mean kcal/mole. Although the agreement is perhaps fortuitous, this is practically the same as the value of 18.66 selected by Hultgren et al. (9), which was obtained by a third-law treatment of several vapor-pressure measurements at lower temperatures.

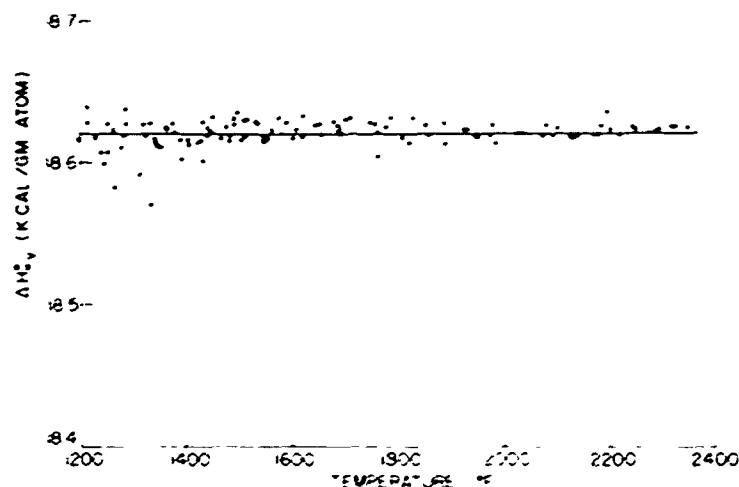


Fig. 3 - Heat of vaporization of monomeric cesium at absolute zero as computed from observed vapor-pressure data

Discussion of Saturation Pressures - Saturation results are presented in Table 4 for cesium samples from two sources, MSA Research Corporation and Dow Chemical Company. Spectrographic analyses of these materials are presented in Table 1. It will be noted that while the impurities differ considerably both as to type and magnitude, the vapor pressures observed are in good agreement. The average deviation of Eq. (1) from the data for the MSAR metal is $\pm 0.25\%$ and for the Dow metal is $\pm 0.32\%$. This agreement confirms that the two samples are effectively equivalent and that the impurities present do not significantly affect the reported vapor pressures.

The measurement of saturation pressures directly with a diaphragm detector is new to the high-temperature field. The relative merits of the apparatus and the uncertainties to be expected in the various measurement parameters were discussed in the potassium report (1). If all known sources of error in the saturation measurements are considered, the probable error in the reported vapor pressure for cesium at 1 atm is $\pm 0.67\%$ and at 34 atm is $\pm 0.49\%$.

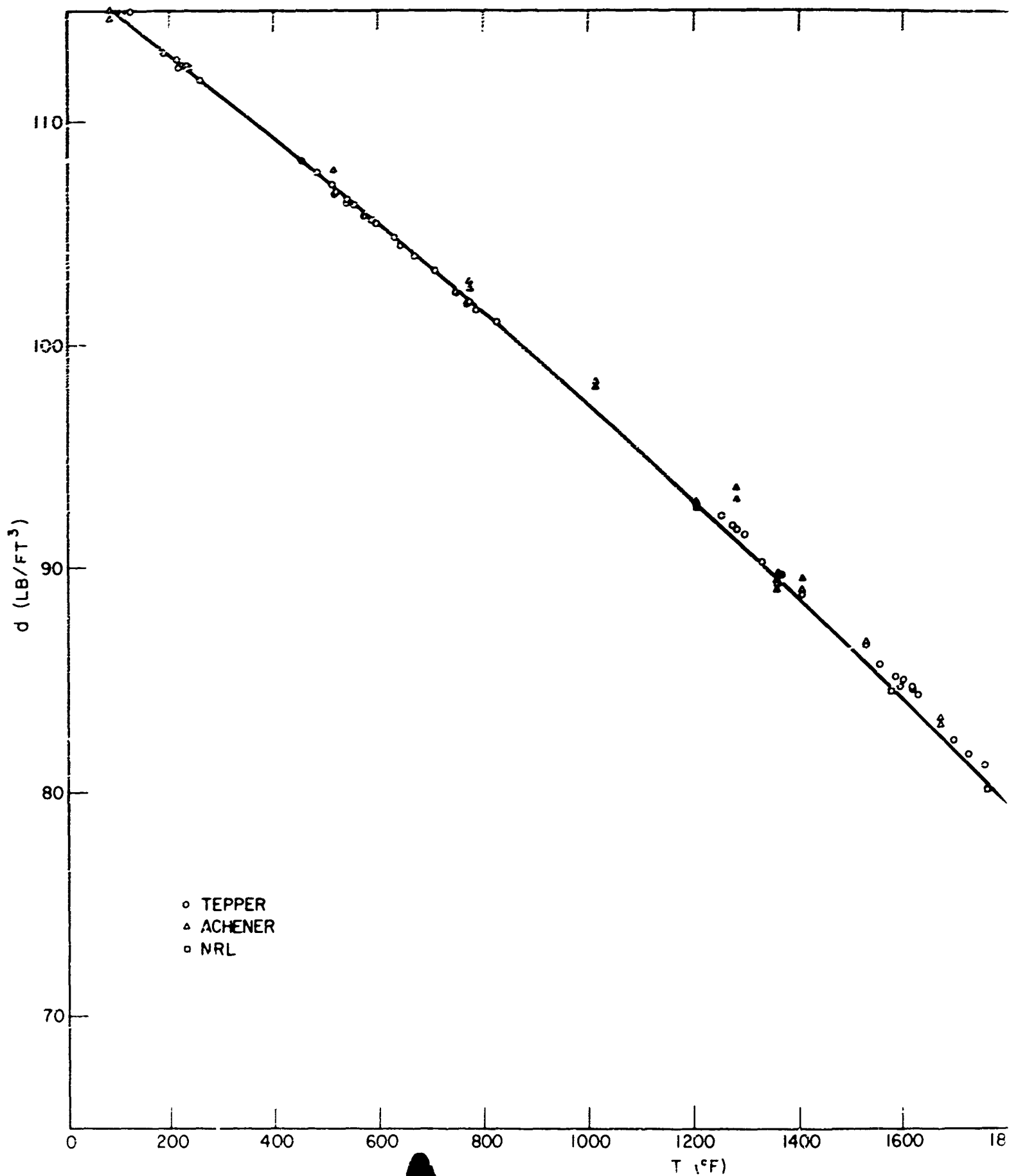


Fig. 4 - Density of liquid cesium

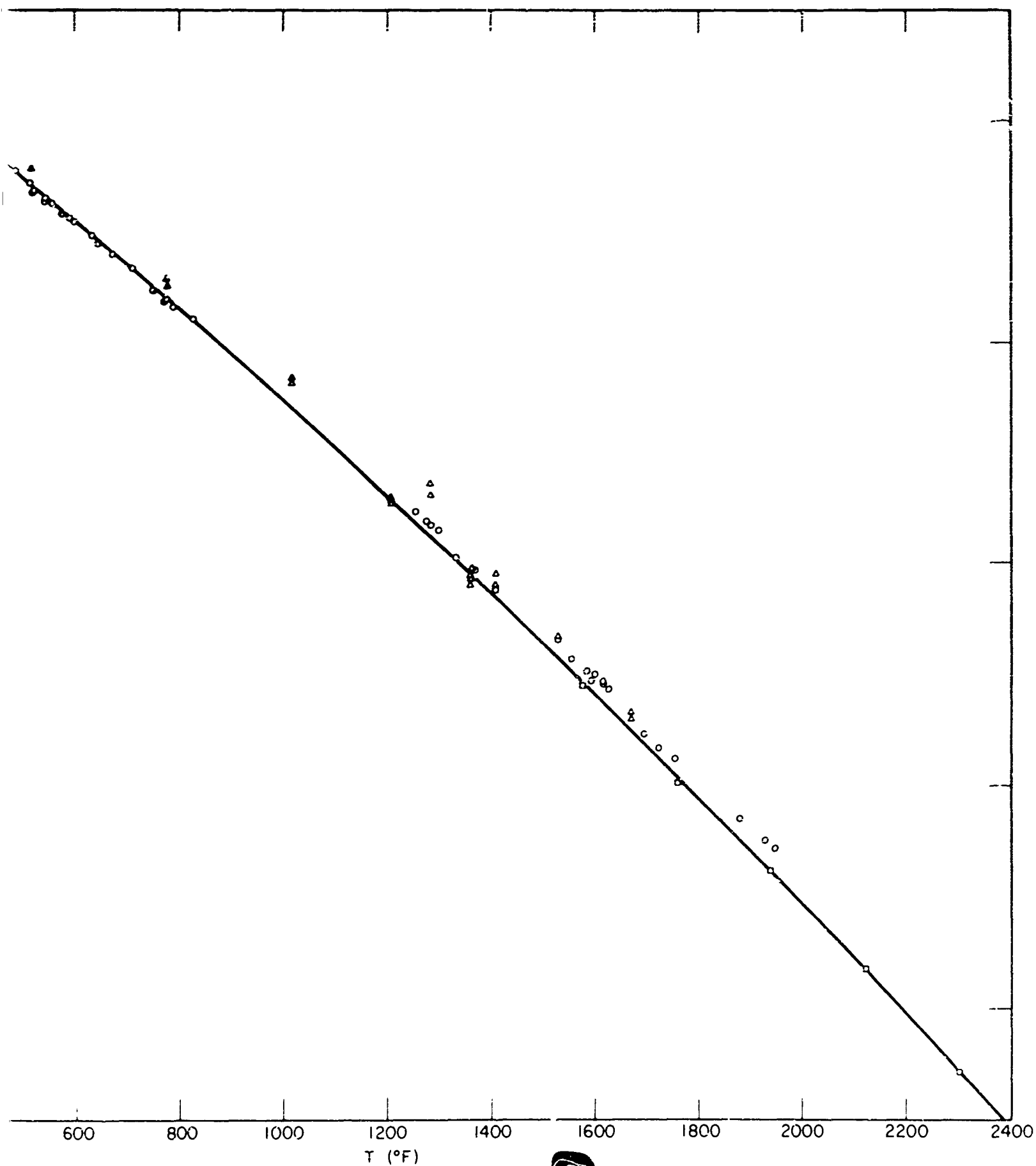


Fig. 4 - Density of liquid cesium.

B

Density Measurements of Liquid Cesium

The density of liquid cesium was determined with columbium-1%zirconium pycnometers of 30 cc nominal volume by the method described for potassium (1). Measured densities over the temperature range from 1577.0° to 2303.8°F are reported in Table 6 and presented graphically in Fig. 4 along with those of two other investigators. The uncertainties to be expected in the various parameters of the NRL density measurements are discussed in the potassium report (1). If all known sources are taken into account, the probable error of the reported densities range from $\pm 0.25\%$ at 1577°F to $\pm 0.30\%$ at 2304°F.

The recommended density equation for liquid cesium from the melting point to 2300°F is

$$d^l = 124.181 - 1.5970 \times 10^{-2} T - 1.6855 \times 10^{-6} T^2. \quad (5)$$

This equation was derived by fitting the best curve to the density determinations of Achener (4), Tepper et al. (5), and NRL (Table 6). These three independent sets of measurements are summarized in Table 7. For each investigation, the temperature range, the general method, and the average deviation of the observed densities from those calculated with Eq. (5) are presented. The three sets of measurements show fair internal consistency over the full temperature range, and it is believed that Eq. (5) will give density values which are accurate to $\pm 0.6\%$ between the melting point and 2300°F.

Table 6
Density of Liquid Cesium

| Temperature (°F) | Density (lb/cu ft) |
|---------------------|-----------------------|
| 1577.0 | 84.563 |
| 1762.2 | 80.209 |
| 1939.9 | 76.267 |
| 2122.5 | 71.845 |
| 2303.8 | 67.189 |

Table 7
Summary of Density Measurements

| Investigator | Method | Temp. Range (°F) | % Average Deviation [Obs. - Calc. (Eq. (5))] Calc. |
|--------------|-------------------------------|---------------------|--|
| | | | |
| Achener | Dilatometric (pycnometers) | (83 to 1671) | ± 0.70 |
| Tepper | Dilatometric | (105 to 1950) | ± 0.35 |
| NRL | Dilatometric (pycnometers) | (1577 to 2304) | ± 0.14 |

SUMMARY OF FUNDAMENTAL PROPERTIES USED IN THE THERMODYNAMIC TREATMENTS

Density of Liquid Cesium

The density of the condensed phase was required to compute the enthalpy of vaporization from the Clapeyron equation and was obtained from Eq. (5).

Enthalpy and Entropy of Monomeric Cesium Vapor

The monomeric gas properties, together with the values selected for the enthalpy of sublimation, largely determine the absolute accuracy of the superheat properties tabulated in Appendixes A and B. The equations for the enthalpy and entropy of the gas were derived directly from the work of Evans et al. (7) and are based on their standard properties over the temperature range from 0° to 3100°F and on the enthalpy of vaporization to 0°R (18.62 mean kcal/mole) as derived in this report. The equations for the monomeric gas at 1 atm (relative to the solid crystal at 0°R) are

$$(h^g)^0 = 252.18 + 0.037361 T + 2480 e^{-31.290/T} \quad (6)$$

$$(s^g)^0 = 0.037361 \ln T + 0.980604 + 0.371 e^{-28.598/T} \quad (7)$$

Specific Heat at Constant Pressure of Monomeric Cesium Vapor

The specific heat of monomeric cesium vapor at constant pressure largely determines the absolute accuracy of the values reported for the specific heat of the equilibrium vapor in Appendix B. The equation for the specific heat of the monomeric gas was derived from the work of Evans et al. (7) and is based on their computed properties over the temperature range from 0° to 2800°F. The relation for the monomeric gas at 1 atm is

$$(c_p^g)^0 = 0.037361 + 1.3099 e^{-25.443/T} \quad (8)$$

Enthalpy and Entropy of Liquid Cesium

The tabulated thermodynamic properties in this report are based on the properties of the monomeric gas at 1 atm, but comparison calculations were made using the properties of the saturated liquid as a starting point. The absolute properties of the liquid (relative to the solid at 0°R) were computed with

$$h_g^l = -2.6969 + 0.05683 T \quad (9)$$

$$T > 1030^\circ \text{R}$$

$$s_g^l = 0.05683 \ln T - 0.19387 \quad (10)$$

$$T > 1030^\circ \text{R}$$

In order to obtain these equations, a knowledge of the specific heat of the liquid was required. In a previous section of this report, a constant value of 0.05683 Btu/lb-°F was shown to give the greatest degree of internal consistency in third-law calculations. A constant value has also been reported in two recent measurements; Tepper et al. (5) reported a value of 0.0546, and Lemmon et al. (8) reported 0.0600. The third-law value of 0.05683 is intermediate between the two published values and was used in deriving Eqs. (9) and (10).

These two equations are based on the absolute properties of solid cesium at 77.0°F by Hultgren et al. (9). Although only a short solidus region remains above this temperature, the change in the properties for this region and the required enthalpy of fusion were taken from the work of Lemmon et al. (8). There is an anomaly (5,8) in the heat-content

curve of the liquid in the temperature range to 570°F. The enthalpy change for Eq. (9) in this region was obtained from Lemmon (8). On the other hand, the entropy equation ignores the anomaly in heat content and was derived by assuming the specific heat of the liquid to be constant for the whole liquid range.

Saturation Pressure of Liquid Cesium

Three equivalent vapor-pressure equations (Eqs. (1), (2), and (3)) were derived from least-squares correlations. All thermodynamic quantities in this report are arbitrarily based on Eq. (1).

Enthalpy and Entropy of Vaporization of Cesium

Heats of vaporization were calculated with

$$\Delta h_v = J p_s \left[\frac{16,211.8}{T} - 0.53290 \right] (v_g^g - v_g^l) \quad (11)$$

which was derived by a differentiation of Eq. (1) and subsequent substitution into the Clapeyron equation. A value of v_g^l at each temperature was obtained from Eq. (5) and a value of v_g^g from the virial equation of state (Eq. (13)).

The heats of vaporization so obtained from the Clapeyron equation are presented graphically in Fig. 5 and are compared with values reported by Achener (4). The four results by Achener were measured directly by noting the heat required to vaporize a given mass of the liquid. The agreement is good; three of Achener's points are within 1% of the corresponding NRL values and the fourth is within 3% of the NRL value.

The entropy of vaporization at each saturation point was obtained by dividing the appropriate enthalpy change by the absolute temperature.

THERMODYNAMIC TREATMENT OF PVT AND ASSOCIATED PROPERTIES

The imperfections which occur in the alkali metal vapors and the various treatments of these imperfections in the reduction of PVT data are discussed at some length in the companion reports (1,2). Quasi-chemical analyses of the PVT data for sodium and potassium have shown that dimeric and, perhaps, tetrameric molecules are present in the metal vapors. From a similar analysis of the cesium system, which is discussed later in this report, it is believed that the major imperfection in cesium also stems from the existence of higher-molecular-weight species.

For a strongly associating gas the important properties (enthalpy, entropy, and specific heat) may be reduced from PVT data by the use of either of two methods, the virial or the quasi-chemical. The two methods were shown for sodium and potassium to be effectively equivalent, so only the virial method was used in the reduction of the cesium data. The virial equation of state for cesium with coefficients through the fifth virial was obtained from raw PVT data and used to compute enthalpies, entropies, specific volumes, and specific heats of the vapor.

The thermodynamic properties of cesium by the virial method were computed along constant temperature lines. The starting point for a particular property could have been

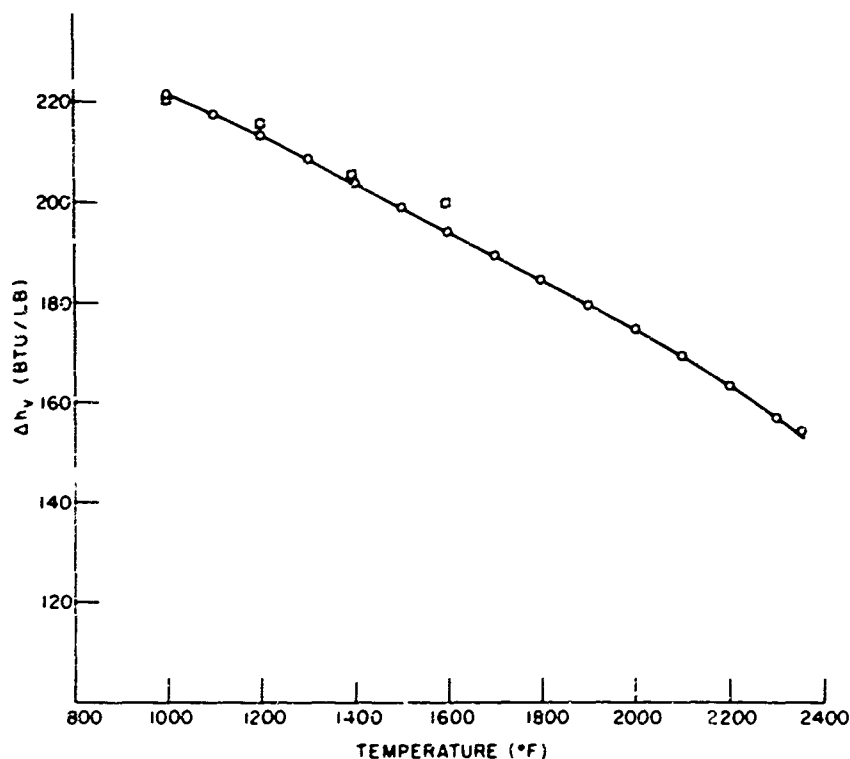


Fig. 5 - Enthalpy of vaporization of cesium
 □ Achener, ○ NRL

the absolute value of that property for either the saturated liquid or the monomeric gas. Therefore, two computational paths exist for obtaining each absolute property in the superheat region. The properties were computed along both paths, and the results are compared in this report.

Virial Coefficients of Cesium

The virial equation of state in its volume expansion form,

$$\frac{p\tilde{V}}{RT} = 1 + \frac{B}{\tilde{V}} + \frac{C}{\tilde{V}^2} + \frac{D}{\tilde{V}^3} + \frac{E}{\tilde{V}^4} + \dots \quad (12)$$

was chosen for the analyses of all three alkali metal systems.

The PVT data for cesium were more precise than those obtained for either sodium or potassium, and the adjustment procedure (1,2) used to facilitate the graphical reduction of the sodium and potassium data was not required. The coefficients, however, were still derived graphically from the PVT data by plotting functions along constant temperature lines. As a first step, $(z - 1)\tilde{V}$ was plotted as a function of $1/\tilde{V}$ for isotherms at 50-degree intervals between 2050° and 2550° F, and preliminary second virial coefficients were obtained as the $\lim_{1/\tilde{V} \rightarrow 0} (z - 1)\tilde{V}$. The final coefficient at each temperature was obtained by adjusting the preliminary value to give the best internal consistency between the low- and high-pressure results as determined from a plot of $[(z - 1)\tilde{V} - B]\tilde{V}$ versus $1/\tilde{V}$. A final plot of $(z - 1)\tilde{V}$ versus $1/\tilde{V}$ is illustrated in Fig. 6 for the isotherm at 2400° F. In the intermediate temperature range from 1600° to 2050° F, final second virial coefficients were taken as the $\lim_{1/\tilde{V} \rightarrow 0} (z - 1)\tilde{V}$. The coefficients for the full measured range from 1550° to 2550° F may be represented by a simple exponential relationship (Eq. (13)).

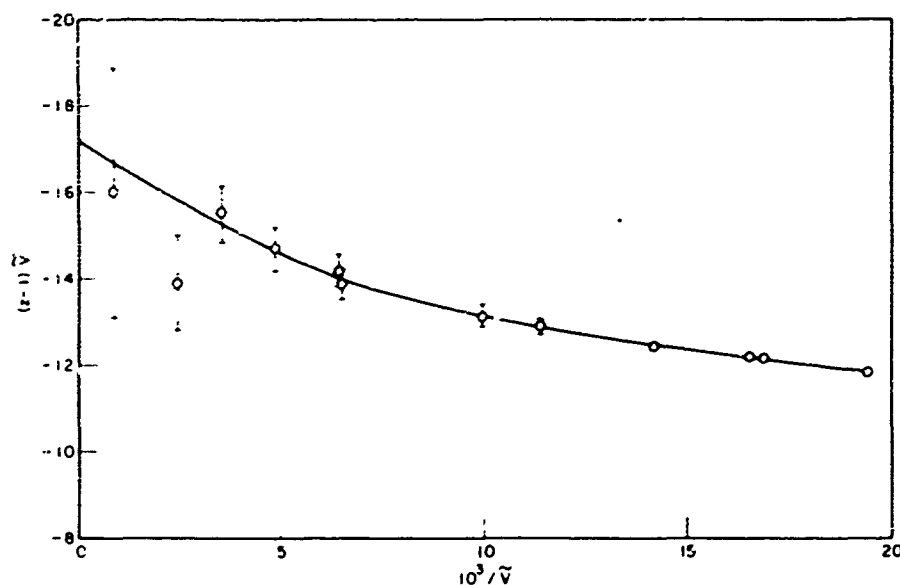


Fig. 6 - Plot of $(z - 1)\tilde{V}$ versus $1/\tilde{V}$ for cesium at 2400 °F
(vertical line for each point represents probable error)

From a preliminary analysis in which third and fourth virial coefficients were derived in the temperature range from 2050° to 2550°F, it was apparent that a fifth virial would be required to precisely fit all the data along any given isotherm. Only a rough value of this higher virial was required, and this was obtained mathematically. With preliminary values for the third virial, $\{(z - 1)\tilde{V} - B\}\tilde{V}^2 - C\tilde{V}\}$ was plotted versus $1/\tilde{V}$ for several higher temperature isotherms, and the value of 600,000 for E was selected from the average apparent slope of the curves at higher pressures.

Final third and fourth virial coefficients in the same temperature range between 2050° and 2550°F were obtained by plotting the revised quantity $\{(z - 1)\tilde{V} - B\}\tilde{V} - E/\tilde{V}^2\}$ versus $1/\tilde{V}$ for isotherms at 50-degree intervals. This is illustrated in Fig. 7 for the isotherm at 2400°F. From the best linear curve for each isotherm the third virial was obtained as the intercept and the fourth as the slope. The fourth virial coefficient may be represented for the full temperature range as a simple first-degree exponential equation in $1/T$ (Eq. (13)). Additional third virial coefficients were obtained in the intermediate temperature range from 1550° to 2050°F by computing the average value of $\{(z - 1)\tilde{V} - B\}\tilde{V} - D/\tilde{V} - E/\tilde{V}^2\}$ for the higher pressure points on each isotherm. The third virial coefficient for the full range from 1550° to 2550°F may be represented by a second-degree exponential equation (Eq. (13)).

Experimental PVT data were also obtained in a lower temperature range between 1550° and 1275°F, but the number of experimental points along an isotherm was insufficient to permit one to obtain reliable virial coefficients by the graphical method. Consequently, before the virial equation of state for cesium was acceptable for calculations below 1550°F, it was necessary to determine its fit to the observed lower temperature data. At temperatures and pressures corresponding to the observed low-temperature states, compressibility factors were calculated and compared to the observed values. The fit of the virial equation of state to the lower temperature data was found to be equivalent to that obtained at higher temperatures.

Virial Equation of State of Cesium

The virial equation of state of cesium with coefficients through the fifth virial is

$$\frac{p\tilde{V}}{RT} = 1 + \frac{B}{\tilde{V}} + \frac{C}{\tilde{V}^2} + \frac{D}{\tilde{V}^3} + \frac{E}{\tilde{V}^4} + \dots \quad (13)$$

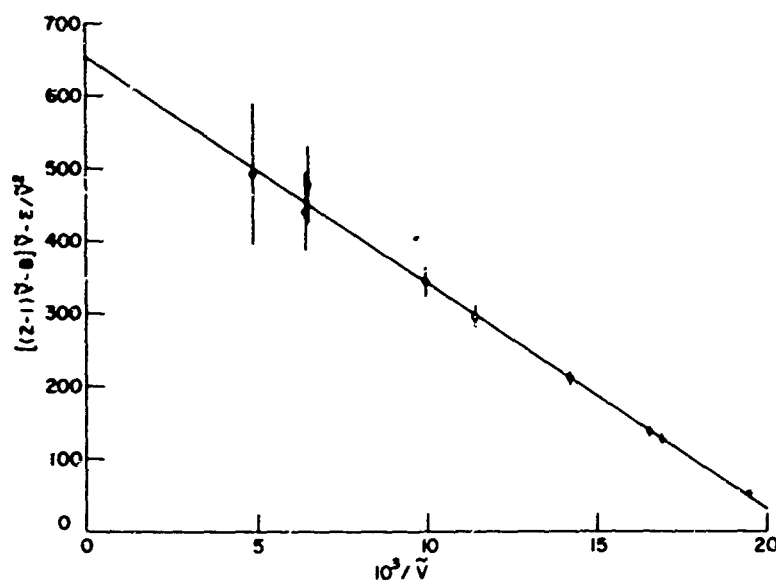


Fig. 7 - Plot of $\{[(z - 1)P - B]P̃ - E/P̃^2\}$ versus $1/P̃$ for cesium at 2400°F (vertical line for each point represents probable error)

where

$$\log |B| = -3.6200 + 4000.0/T + \log T$$

$$B < 0$$

$$\log C = 3.3551 - 5331.5/T + 10.825 \times 10^6/T^2$$

$$C > 0$$

$$\log |D| = 4.1856 + 880/T$$

$$D < 0$$

$$E = +600,000.$$

The degree to which the virial equation was fitted to the measured data is shown graphically in Fig. 8, where compressibility isotherms generated with Eq. (13) are compared to experimental compressibilities at 100-degree intervals from 1350° to 2550°F. The degree of fit can also be shown mathematically. For example, all the observed specific-volume data in Table 2 (or compressibility factors derived from that data) may be calculated from the virial equation with an average deviation of only $\pm 0.15\%$. It is significant that this deviation is of a magnitude predicted by random and systematic errors in the null-point measurements.

Thermodynamic Properties of Cesium by the Virial Method (Monomeric Gas Path)

Expressions for the thermodynamic properties in terms of the second and third virial coefficients were derived by Hirschfelder et al. (10). By the same method, similar equations were derived to include the fourth and fifth virial coefficients. These equations which were used to compute the thermodynamic properties of cesium vapor (Appendixes A and B) are presented below.

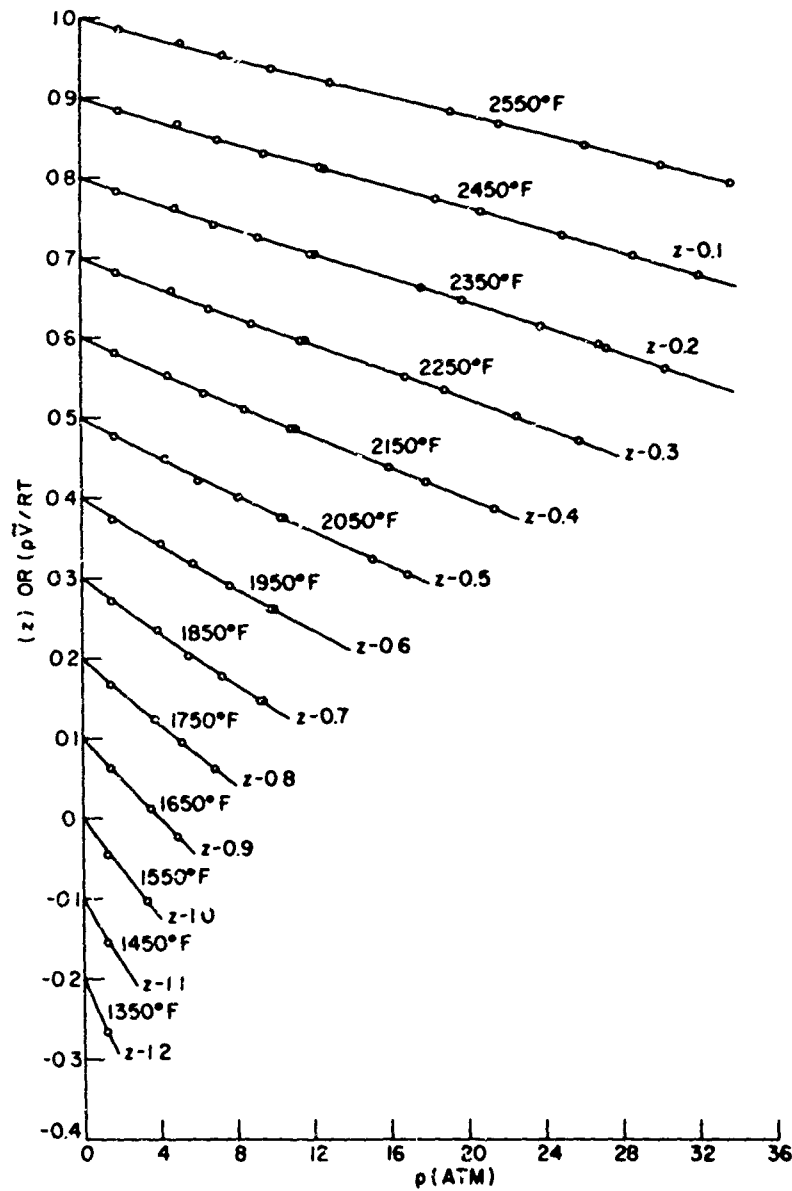


Fig. 8 - Compressibility of cesium vapor
at several temperatures

Enthalpy, Entropy, and Specific Heat of Saturated and Superheated Vapor - These properties at all vapor states were computed along isotherms using the following equations:

$$h_i^g = (h^g)^o + \frac{RT}{M_1} \left\{ \frac{1}{\tilde{V}} \left[B - T \left(\frac{dB}{dT} \right) \right] + \frac{1}{\tilde{V}^2} \left[C - \frac{T}{2} \left(\frac{dC}{dT} \right) \right] + \frac{1}{\tilde{V}^3} \left[D - \frac{T}{3} \left(\frac{dD}{dT} \right) \right] + \frac{1}{\tilde{V}^4} \left[E - \frac{T}{4} \left(\frac{dE}{dT} \right) \right] \right\} \quad (14)$$

$$s_i^g = (s^g)^o - \frac{R}{M_1} \left\{ \ln p - \ln \frac{p\tilde{V}}{RT} + \frac{B}{\tilde{V}} + \frac{T}{\tilde{V}} \left(\frac{dB}{dT} \right) + \frac{C}{2\tilde{V}^2} + \frac{T}{2\tilde{V}^2} \left(\frac{dC}{dT} \right) + \frac{D}{3\tilde{V}^3} + \frac{T}{3\tilde{V}^3} \left(\frac{dD}{dT} \right) + \frac{E}{4\tilde{V}^4} + \frac{T}{4\tilde{V}^4} \left(\frac{dE}{dT} \right) \right\} \quad (15)$$

$$(c_p^g)_1 = (c_p^g)_s - \frac{R}{M_1} + \frac{R}{M_1} \left\{ \frac{\left[1 + \frac{1}{\tilde{V}} \left(B - T \frac{dB}{dT} \right) + \frac{1}{\tilde{V}^2} \left(C - T \frac{dC}{dT} \right) + \frac{1}{\tilde{V}^3} \left(D - T \frac{dD}{dT} \right) + \frac{1}{\tilde{V}^4} \left(E - T \frac{dE}{dT} \right) \right]^2}{\left[1 + 2 \frac{B}{\tilde{V}} + 3 \frac{C}{\tilde{V}^2} + 4 \frac{D}{\tilde{V}^3} + 5 \frac{E}{\tilde{V}^4} \right]} \right. \\ \left. - \frac{RT}{\tilde{V} M_1} \left\{ \left(T \frac{d^2 B}{dT^2} - 2 \frac{dB}{dT} \right) + \frac{1}{2 \tilde{V}} \left(T \frac{d^2 C}{dT^2} - 2 \frac{dC}{dT} \right) + \frac{1}{2 \tilde{V}^2} \left(T \frac{d^2 D}{dT^2} - 2 \frac{dD}{dT} \right) + \frac{1}{4 \tilde{V}^3} \left(T \frac{d^2 E}{dT^2} - 2 \frac{dE}{dT} \right) \right\} \right\} \quad (16)$$

Specific Volume of Saturated and Superheated Vapor - This property at all the vapor states in Appendixes A and B was computed from the virial equation of state (Eq. (13)) by a trial and error solution.

Enthalpy and Entropy of the Condensed Phase - These properties of the saturated liquid (Appendix A) at each temperature were obtained by subtracting the enthalpy or entropy of vaporization from the corresponding properties of the saturated vapor.

Thermodynamic Properties of Cesium by the Virial Method (Liquid Path)

Expressions for the thermodynamic quantities with the properties of the condensed liquid as a base were derived directly from those in the preceding section. These new equations together with a procedural outline of the methods of calculation are presented below.

Enthalpy, Entropy, and Specific Heat of the Saturated Vapor - The enthalpy or entropy of the saturated vapor at a given temperature was obtained by adding the enthalpy or entropy of vaporization to the corresponding property of the saturated liquid. The specific heat at saturation was obtained by numerically evaluating at 50-degree intervals the differential

$$(c_p^g)_s = \left[\left(\frac{\partial h}{\partial T} \right)_p \right]_s = \left[\left(\frac{\partial h}{\partial T} \right)_p \right]_s \quad (17)$$

Enthalpy, Entropy, and Specific Heat of Superheated Vapor - These properties in the superheat region were computed along constant temperature lines with each saturation state as a starting point. The general equations in virial form are

$$h_1^g = h_s^g - \frac{RT}{M_1} \left[\frac{1}{\tilde{V}} \left(B - T \frac{dB}{dT} \right) + \frac{1}{\tilde{V}^2} \left(C - T \frac{dC}{dT} \right) + \frac{1}{\tilde{V}^3} \left(D - T \frac{dD}{dT} \right) + \frac{1}{\tilde{V}^4} \left(E - T \frac{dE}{dT} \right) \right]_{\tilde{V}_1}^{\tilde{V}_s} \quad (18)$$

$$s_1^g = s_s^g + \frac{R}{M_1} \left[\ln p - \ln \frac{p \tilde{V}}{RT} + \frac{B}{\tilde{V}} + \frac{T dB}{dT} + \frac{C}{2 \tilde{V}^2} + \frac{T}{2 \tilde{V}^2} \frac{dC}{dT} + \frac{D}{3 \tilde{V}^3} + \frac{T}{3 \tilde{V}^3} \frac{dD}{dT} + \frac{E}{4 \tilde{V}^4} + \frac{T}{4 \tilde{V}^4} \frac{dE}{dT} \right]_{\tilde{V}_1}^{\tilde{V}_s} \quad (19)$$

$$\begin{aligned}
 (c_p^g)_1 = (c_p^g)_s - \frac{R}{M_1} & \left[\frac{\left\{ 1 - \frac{1}{\tilde{v}} \left(B + T \frac{dB}{dT} \right) - \frac{1}{\tilde{v}^2} \left(C + T \frac{dC}{dT} \right) - \frac{1}{\tilde{v}^3} \left(D + T \frac{dD}{dT} \right) - \frac{1}{\tilde{v}^4} \left(E + T \frac{dE}{dT} \right) \right\}^2}{\left\{ 1 - \frac{2B}{\tilde{v}} - \frac{3C}{\tilde{v}^2} - \frac{4D}{\tilde{v}^3} - \frac{5E}{\tilde{v}^4} \right\}} \right]_{\tilde{v}_1}^{\tilde{v}_s} \\
 & - \frac{RT}{\tilde{v}_1 M_1} \left[\left(T \frac{d^2 B}{dT^2} - 2 \frac{dB}{dT} \right) - \frac{1}{2\tilde{v}} \left(T \frac{d^2 C}{dT^2} - 2 \frac{dC}{dT} \right) - \frac{1}{3\tilde{v}^2} \left(T \frac{d^2 D}{dT^2} - 2 \frac{dD}{dT} \right) - \frac{1}{4\tilde{v}^3} \left(T \frac{d^2 E}{dT^2} - 2 \frac{dE}{dT} \right) \right]_{\tilde{v}_1}^{\tilde{v}_s} \quad (20)
 \end{aligned}$$

A Comparison of the Monomeric Gas Path and the Liquid Path for Thermodynamic Calculations

The thermodynamic properties of cesium were computed along constant temperature lines. The starting point for a particular property could have been the absolute value of that property for either the saturated liquid or the monomeric gas at 1 atm. The three properties (enthalpy, entropy, and specific heat) of the superheated vapor were computed by both paths, and values at selected states are compared in Table 8. In the temperature range from 1250° to 2350°F, absolute enthalpies in the superheat region, based on enthalpies of the saturated liquid, were 0.2 to 6.9 Btu/lb (approximately 0.1 to 2.0%) lower than corresponding values based on the monomeric gas enthalpies. Likewise, entropies by the liquid path were 0 to 0.0025 Btu/lb-°F (approximately 0 to 0.8%) lower, and specific heats differed by 5.3 to 31%.

The small divergence of the absolute enthalpies (Table 8) as computed along the two paths over the temperature range from 1250° to 2050°F suggests that the selected value of either the specific heat of the liquid or its temperature coefficient is slightly in error. It will also be noted that the enthalpy of the superheated vapor at a given pressure, if computed from the liquid base, exhibits an abnormal change in slope at temperatures above 2100°F. This is reflected in the specific heat values which at 2250°F are 16 to 31% lower and at 2350°F are 7 to 15% higher than those computed by the monomeric gas path. Part of this apparent error at higher temperatures in the enthalpy as computed along the liquid path may have resulted from errors in various quantities along the two computational paths. It is believed that a large part must also be attributed either to errors in the enthalpy of vaporization resulting from small inconsistencies in the virial equation of state or to error generated by the rather arbitrary selection and extrapolation of the liquid specific heat.

Engineering design calculations put prime emphasis on the change in enthalpy or entropy when moving from one state to another rather than on their absolute values; therefore, the choice of path is of minor importance for both these properties. However, the specific heat of the vapor would be expected to be more accurate if computed from the monomeric gas, since this path is independent of vaporization quantities and does not require a knowledge of the specific heat of the liquid. Therefore, the monomeric gas path has been chosen to compute all the tabular properties in this report.

DISCUSSION OF QUASI-CHEMICAL EQUATION OF STATE AND THE COMPOSITION OF CESIUM VAPOR

The PVT results for sodium and potassium were satisfactorily interpreted by a quasi-chemical approach based on the assumption that each metal vapor is an ideal mixture of monomeric, dimeric, and tetrameric species. Although this model of the physical

Table 3
Comparison of Monomeric Gas and Liquid Path Calculations

| Temp. (°F) | Pressure (atm) | Monomeric Gas Path | | | Liquid Path | | |
|---------------|-------------------|--------------------|---------------|---------------|---------------|---------------|---------------|
| | | $\frac{1}{2}$ | $\frac{1}{3}$ | $\frac{1}{4}$ | $\frac{1}{2}$ | $\frac{1}{3}$ | $\frac{1}{4}$ |
| 1250 | 1.0 | 306.4 | 0.3541 | 0.0653 | 306.2 | 0.3540 | 0.0619 |
| | 0.2 | 314.1 | 0.3818 | 0.0435 | 313.9 | 0.3817 | 0.0400 |
| 1450 | 2.0 | 312.4 | 0.3479 | 0.0645 | 311.4 | 0.3473 | 0.0602 |
| | 1.0 | 317.9 | 0.3605 | 0.0514 | 316.9 | 0.3600 | 0.0471 |
| | 0.2 | 322.4 | 0.3864 | 0.0402 | 321.4 | 0.3859 | 0.0360 |
| 1650 | 5.0 | 313.5 | 0.3361 | 0.0719 | 311.7 | 0.3353 | 0.0685 |
| | 1.0 | 327.4 | 0.3653 | 0.0447 | 325.6 | 0.3644 | 0.0413 |
| | 0.2 | 330.3 | 0.3904 | 0.0388 | 328.5 | 0.3895 | 0.0354 |
| 1850 | 10.0 | 315.0 | 0.3280 | 0.0748 | 312.5 | 0.3268 | 0.0707 |
| | 5.0 | 326.4 | 0.3420 | 0.0582 | 323.9 | 0.3409 | 0.0541 |
| | 1.0 | 336.0 | 0.3692 | 0.0416 | 333.6 | 0.3691 | 0.0375 |
| | 0.2 | 338.0 | 0.3939 | 0.0382 | 335.5 | 0.3928 | 0.0342 |
| 2050 | 18.0 | 315.9 | 0.3212 | 0.0756 | 312.2 | 0.3196 | 0.0657 |
| | 15.0 | 320.6 | 0.3252 | 0.0718 | 316.8 | 0.3237 | 0.0619 |
| | 10.0 | 328.7 | 0.3336 | 0.0623 | 324.9 | 0.3321 | 0.0524 |
| | 5.0 | 337.2 | 0.3465 | 0.0503 | 333.4 | 0.3449 | 0.0404 |
| | 1.0 | 344.2 | 0.3726 | 0.0400 | 340.4 | 0.3710 | 0.0301 |
| | 0.2 | 345.6 | 0.3970 | 0.0379 | 341.8 | 0.3955 | 0.0280 |
| 2250 | 25.0 | 321.2 | 0.3193 | 0.0742 | 314.9 | 0.3170 | 0.0625 |
| | 20.0 | 327.6 | 0.3244 | 0.0684 | 321.3 | 0.3220 | 0.0567 |
| | 15.0 | 333.9 | 0.3303 | 0.0616 | 327.6 | 0.3280 | 0.0500 |
| | 10.0 | 340.2 | 0.3381 | 0.0541 | 333.9 | 0.3357 | 0.0424 |
| | 5.0 | 346.8 | 0.3501 | 0.0459 | 340.4 | 0.3478 | 0.0343 |
| | 1.0 | 352.1 | 0.3756 | 0.0392 | 345.8 | 0.3732 | 0.0275 |
| | 0.2 | 353.2 | 0.3999 | 0.0378 | 346.9 | 0.3976 | 0.0261 |
| 2350 | 33.0 | 318.9 | 0.3153 | 0.0768 | 312.0 | 0.3129 | 0.0824 |
| | 25.0 | 328.4 | 0.3219 | 0.0697 | 321.6 | 0.3196 | 0.0753 |
| | 20.0 | 334.2 | 0.3268 | 0.0638 | 327.4 | 0.3243 | 0.0694 |
| | 15.0 | 339.8 | 0.3325 | 0.0577 | 333.0 | 0.3300 | 0.0632 |
| | 10.0 | 345.5 | 0.3400 | 0.0512 | 338.7 | 0.3375 | 0.0568 |
| | 5.0 | 351.3 | 0.3518 | 0.0445 | 344.5 | 0.3493 | 0.0500 |
| | 1.0 | 356.0 | 0.3770 | 0.0389 | 349.2 | 0.3746 | 0.0445 |
| | 0.2 | 357.0 | 0.4013 | 0.0378 | 350.1 | 0.3988 | 0.0433 |

state of the vapor was believed to be the most probable, other models including several imperfect mixtures of two or more molecular species were shown to be equally effective in comparable quasi-chemical treatments. It was concluded from this study of molecular models (2) that all close-approach imperfections may be properly treated from a thermodynamic standpoint as either interactions of the van der Waals type or as molecular associations. It then follows that the molecular species present in a particular metal vapor cannot be positively identified from an analysis of its PVT data. Even so, a quasi-chemical study of the cesium PVT data was made in the hope that this analysis, combined with those previously made for sodium and potassium, would provide some evidence as to the actual molecular state of an alkali metal vapor.

For the quasi-chemical analysis of an alkali metal vapor, the association of the vapor into ideal molecular compounds can be represented by a series of independent equilibria of the type, $v_1 = v_2$. For such a system, the apparent equilibrium constant of dimerization k'_2 (when all association is taken to be dimerization), can be expressed as a power series (11)

$$k'_2 = k_2 + 2k_3p + 3k_4p^2 + 2k_5p^3 + 2k_6k_4p^4 + \dots \quad (21)$$

in terms of the pressure and the true equilibrium constants of the association reactions. The apparent dimerization constants at any given temperature may be readily computed from the raw PVT data, and the relationship of these apparent constants to pressure may be used to predict the compounds present in the vapor.

The apparent dimerization constant k'_2 for cesium was computed for each experimental point at a temperature of 2400° F, and these apparent constants are shown plotted against p^2 in Fig. 9. Similar plots for the sodium and potassium systems were effectively linear and predicted the existence of the tetramer as the higher-molecular-weight species. It will be noted that cesium appears to require an even higher degree of imperfection to satisfy the quasi-chemical picture. This additional imperfection may be in the form of associations higher than the tetramer or in gas imperfections of the interaction type. In any event, a vapor model involving a perfect mixture of monomeric, dimeric, and tetrameric species is not satisfactory for cesium.

It has been mentioned that in the companion reports (1,2) several molecular models provided satisfactory quasi-chemical fits to the PVT data for the sodium and potassium systems. The principal model tested, other than the perfect mixture of monomeric, dimeric, and tetrameric species, was an imperfect mixture of monomeric and dimeric species. The cesium results were likewise analyzed with this model. A simplified van der Waals equation was again chosen to treat the gas imperfections (interactions not

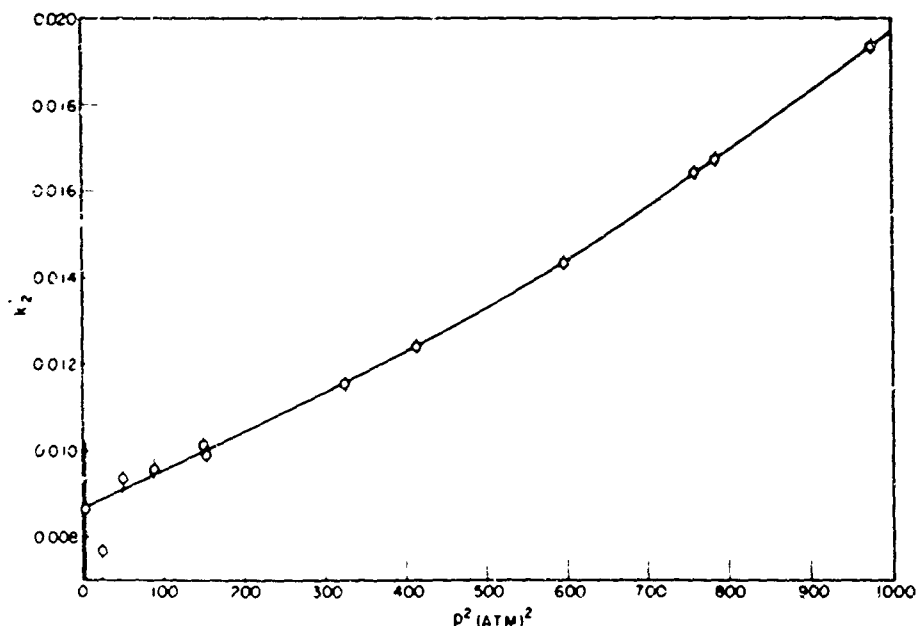


Fig. 9 - Plot of k'_2 versus p^2 for cesium at 2400° F (vertical line for each point represents probable error)

leading to stable molecules). This van der Waals relationship

$$\left(p + \frac{\tilde{a}_1}{\tilde{v}^2}\right)(\tilde{v} - \tilde{b}_1) = \frac{\tilde{u}_1 RT}{\tilde{v}_s} \quad (22)$$

was developed by Vukalovich et al. (12) for an associating gas. For this equation the excluded volume coefficient \tilde{b}_1 was reliably estimated (1) from the condensed volume of the vapor, but the pressure coefficient \tilde{a}_1 had to be obtained empirically. This latter coefficient was assumed to be constant and was evaluated by selecting a value for which the corresponding dimerization constants were independent of pressure along isotherms for the full temperature range. The object was to see whether or not this physical picture of the vapor would correlate with the PVT results, and no attempt was made to determine exact equational fits. It was shown, however, that an effective equation of state could be obtained in terms of Eq. (22) and the relationship $k_2 = A + B/T$ for the corresponding dimerization reaction.

A direct implication of this analysis is that other physical models of the vapor, including an imperfect mixture of monomeric, dimeric, and tetrameric species, would also satisfy the cesium PVT data. It is believed that any one of these quasi-chemical equations of state, if it had been developed, would have been equivalent to the virial form and could also have been used to derive the thermodynamic properties of the vapor. Quasi-chemical equations are more satisfactory for extrapolation of the thermodynamic quantities beyond the measured range of the PVT data. If an extrapolation of the cesium data becomes important in the future, a second equation of state will be developed.

This study, unfortunately, gives no definitive insight into the composition of cesium vapor. The magnitudes of the pressure coefficients in the van der Waals equation, which are required to correlate the data if one assumes either an imperfect mixture of monomeric and dimeric species, or an imperfect mixture of monomeric, dimeric, and trimeric species, do appear to be high. This suggests that the correct model is either an imperfect mixture of monomeric, dimeric, and tetrameric species or a similar mixture of near perfect gases with a fourth species of molecular weight higher than the tetramer.

Equilibrium Constants of the Dimerization Reaction in Cesium Vapor - Although the higher-molecular-weight reactions in cesium vapor could not be identified, it was still possible to obtain reliable dimerization constants. These were obtained by plotting k_2' versus p^2 for isotherms at 50-degree intervals from 1750° to 2550° F and taking the $\lim k_2'$ for each isotherm as $p^2 \rightarrow 0$. This procedure is illustrated in Fig. 10 for isotherms at 100-degree intervals over the temperature range. It will be noted upon close inspection of this figure that the low-pressure experiments for cesium accurately define the intercepts. Thus, the magnitudes of the dimerization constants are not influenced by our lack of knowledge regarding the imperfections present in the vapor.

The observed dimerization constants are shown graphically in Fig. 11. They are well represented by the equation

$$\log k_2 = -3.6501 + \frac{4570}{T} \quad (23)$$

Enthalpy of the Dimeric Reaction in Cesium Vapor - The enthalpy of dimerization was obtained with the van't Hoff equation

$$\frac{d \ln k_2}{dT} = \frac{\Delta H_2^0}{RT^2} \quad (24)$$

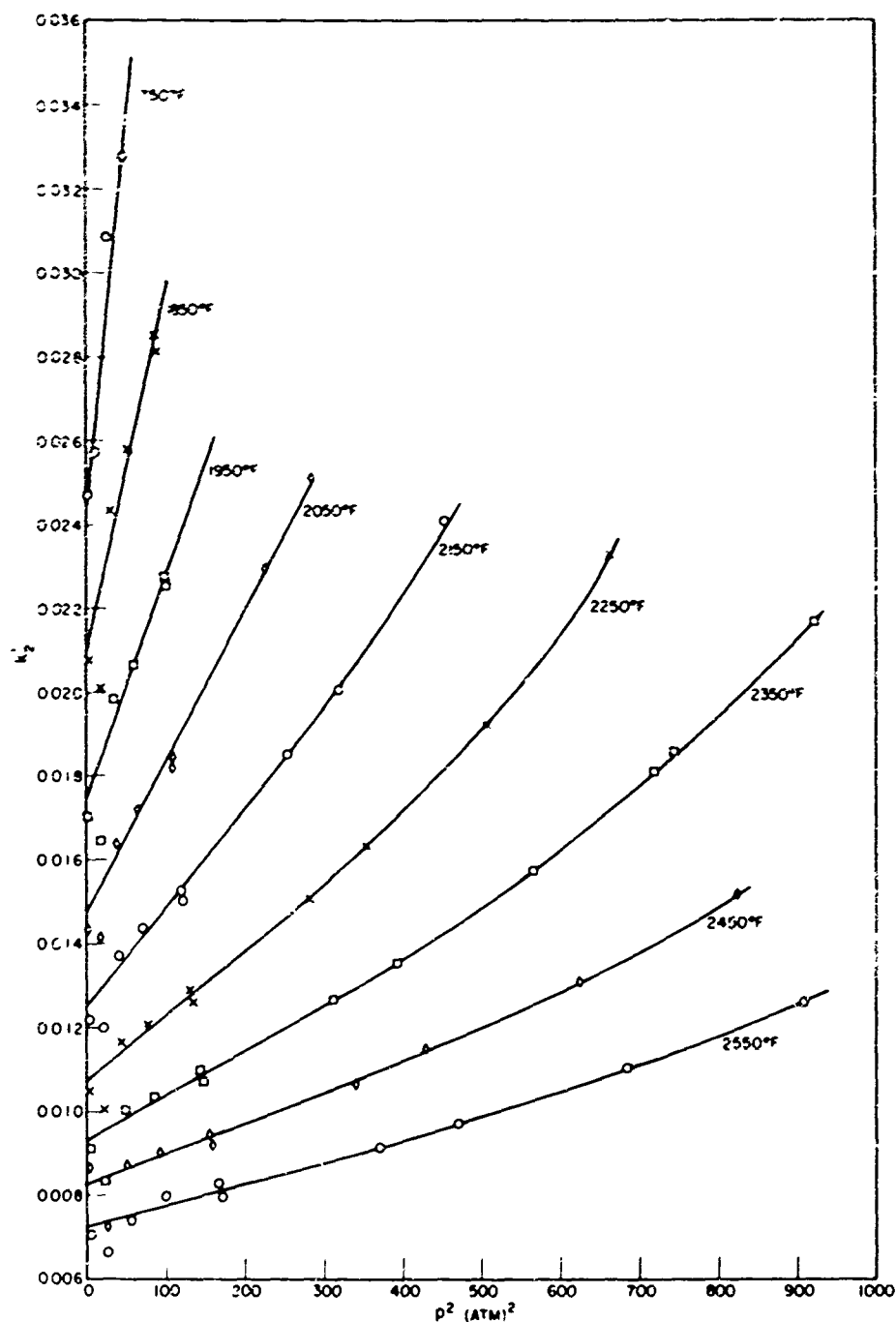


Fig. 10 - Apparent dimerization constants of cesium vapor at several temperatures

by substituting the known differential from Eq. (23). The standard enthalpy so obtained is

$$2Cs \rightleftharpoons Cs_2, \Delta H_2 = -20,900 \text{ Btu/lb-mole or}$$

$$-11.61 \text{ mean kcal/mole.}$$

The association enthalpy at absolute zero of the dimeric reaction was calculated by two methods. A value of -10.7 kcal/mole was obtained at an average temperature of 2250°F with the equation

$$(\Delta H_0^0)_2 = \Delta H_2^0 - \Delta(H^0 - H_0^0)_{2Cs}^0 \quad (25)$$

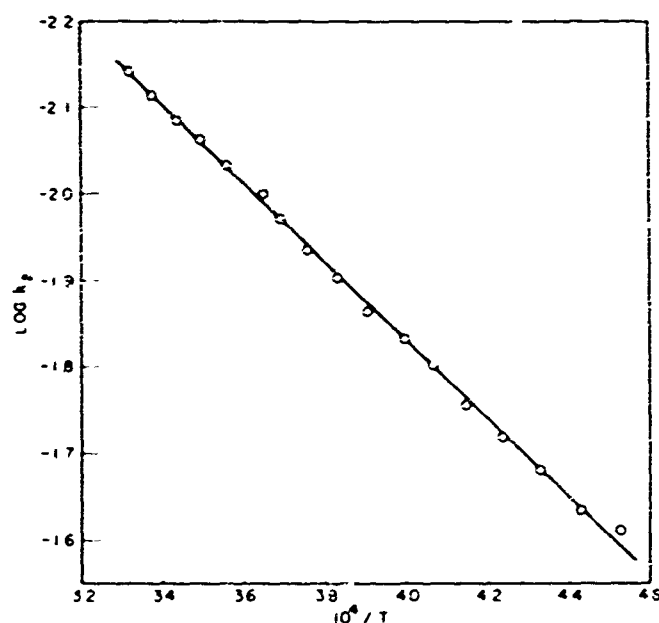


Fig. 11 - Equilibrium constants of dimerization reaction in cesium vapor

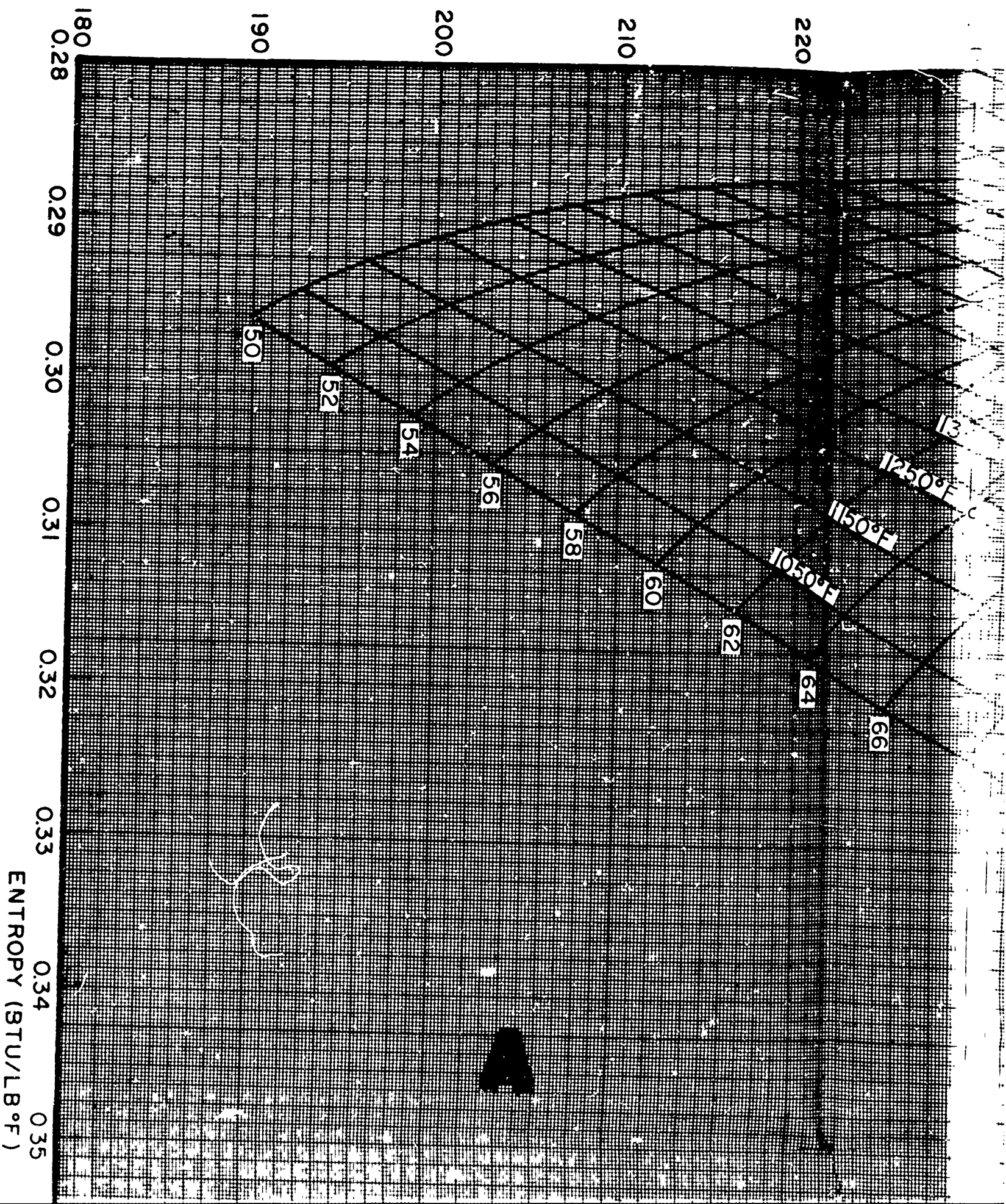
using the observed value of -11.6 for ΔH_2° and the tabular values of Evans et al. (7) for the enthalpy functions. Another value of -11.0 ± 0.1 kcal/mole (which is an average for the temperature range from 2000° to 2400°F) was obtained with the equation

$$\frac{(\Delta H_2^\circ)_2}{T} = R \ln k_2 - \Delta \left[\frac{F^\circ - H_0^\circ}{T} \right]_{2Cs_2}^{Cs_2} \quad (26)$$

using observed equilibrium constants and the free-energy functions of Evans. The difference between the values as computed by the two methods may be the result of errors in either of the thermal functions or in either of the observed quantities. In any event, since the observed standard enthalpy is probably more reliable than the equilibrium constant and the computed enthalpy function is probably more reliable than the free-energy function, the value of -10.7 is believed to be the more reliable one. This is in reasonable agreement with the spectroscopic value of -10.38 by Herzberg (13).

DISCUSSION OF THERMODYNAMIC AND ENGINEERING PROPERTIES OF CESIUM

The engineering and thermodynamic properties of cesium, which are presented in Appendixes A and B and in the large Mollier plot (Fig. 12) were computed by the virial method and are based on the properties of the monomeric gas at 1 atm. Two property relationships, the virial equation of state and the vapor-pressure equation, were used with the basic thermodynamic relationships to derive superheat and saturation properties. The virial equation was reduced from PVT data covering a pressure range of 1.12 to 33.2 atm and a temperature range of 1305° to 2571°F . The vapor-pressure equation represents saturation data covering a range of 1.00 to 33.5 atm. Since the reported properties have been limited to a pressure of 34.0 atm and to a temperature of 2550°F , the range of the observed data covers all states in Appendixes A and B except those with pressures below 1.12 atm. For these lower pressure states, short extrapolations with Eqs. (1) and (13) were required. The reported properties have been examined by several methods and evaluated for internal consistency. It is believed that they represent the best values and that they will be satisfactory for any current calculation required in the design of turbines using cesium as working fluid.



ENTH T
270

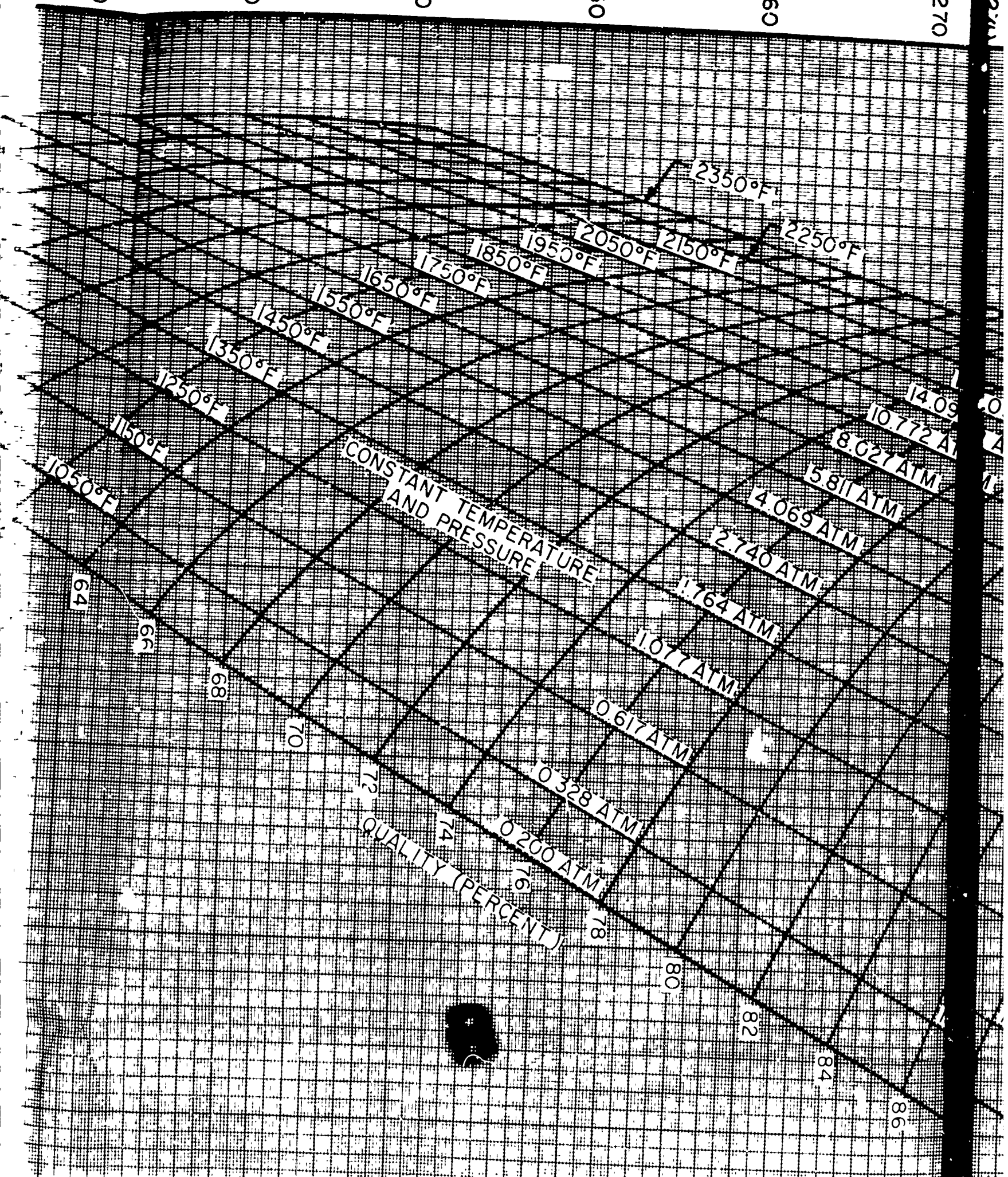
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230

220



ENTHALPY (BTU/LB)

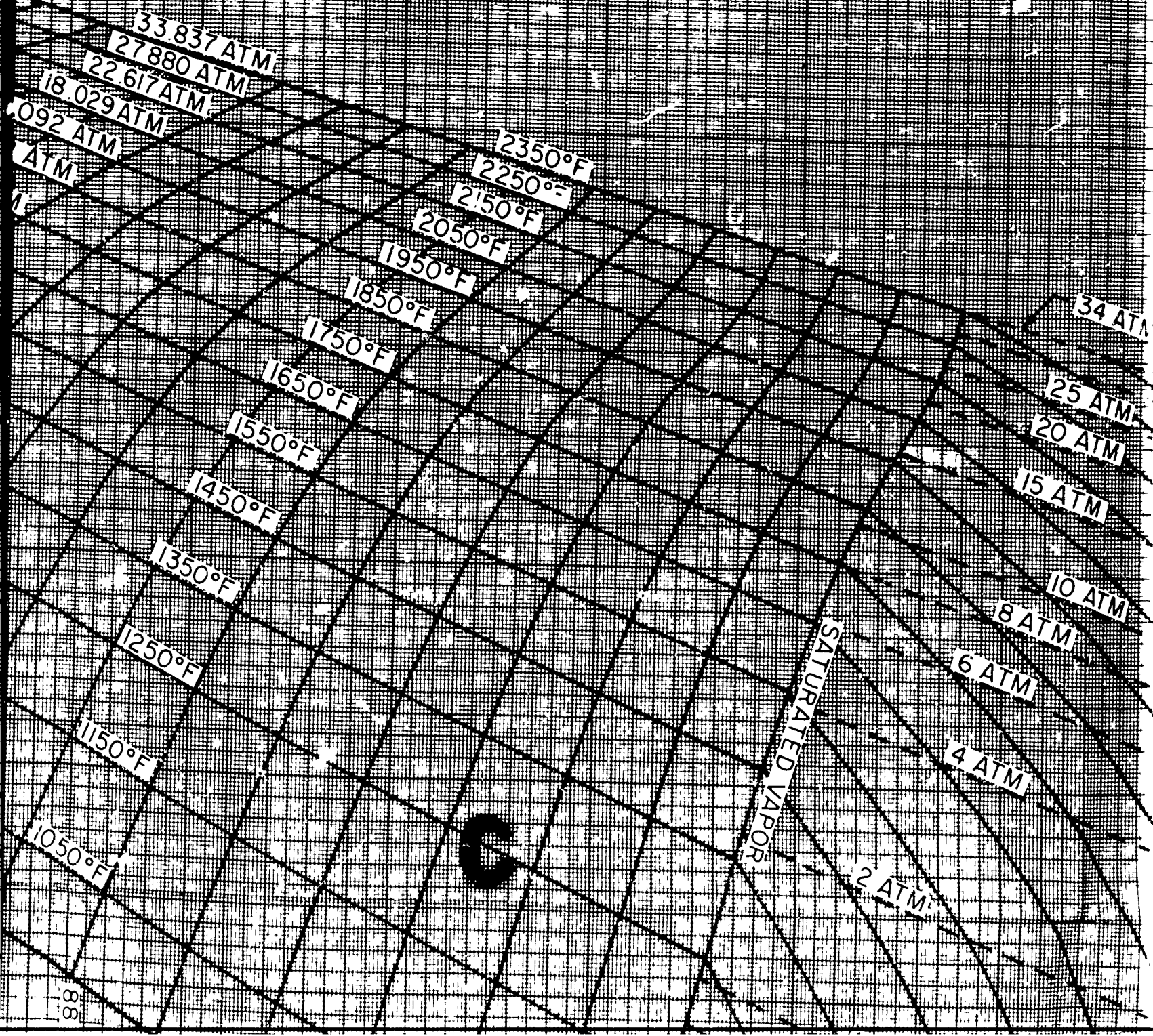
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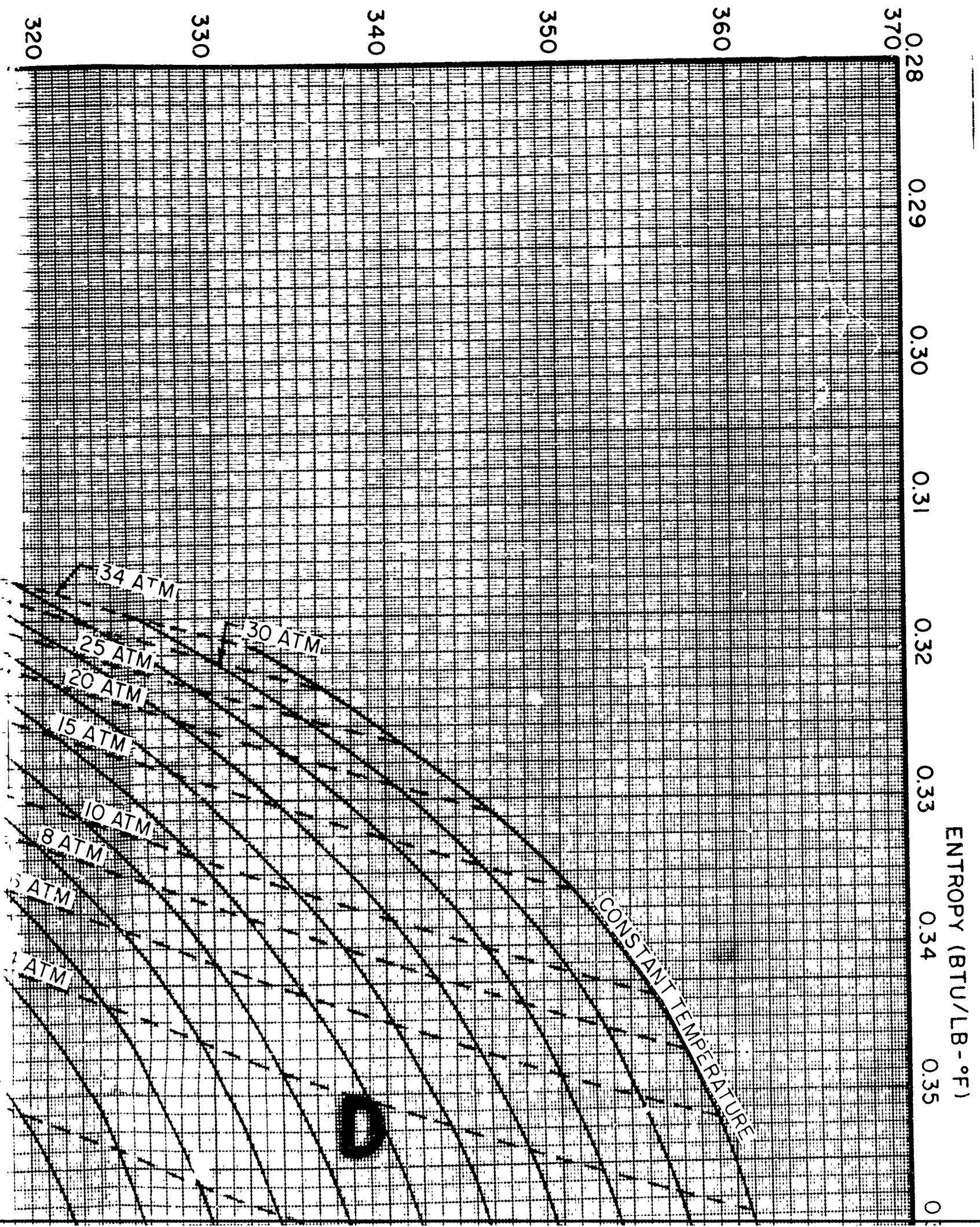
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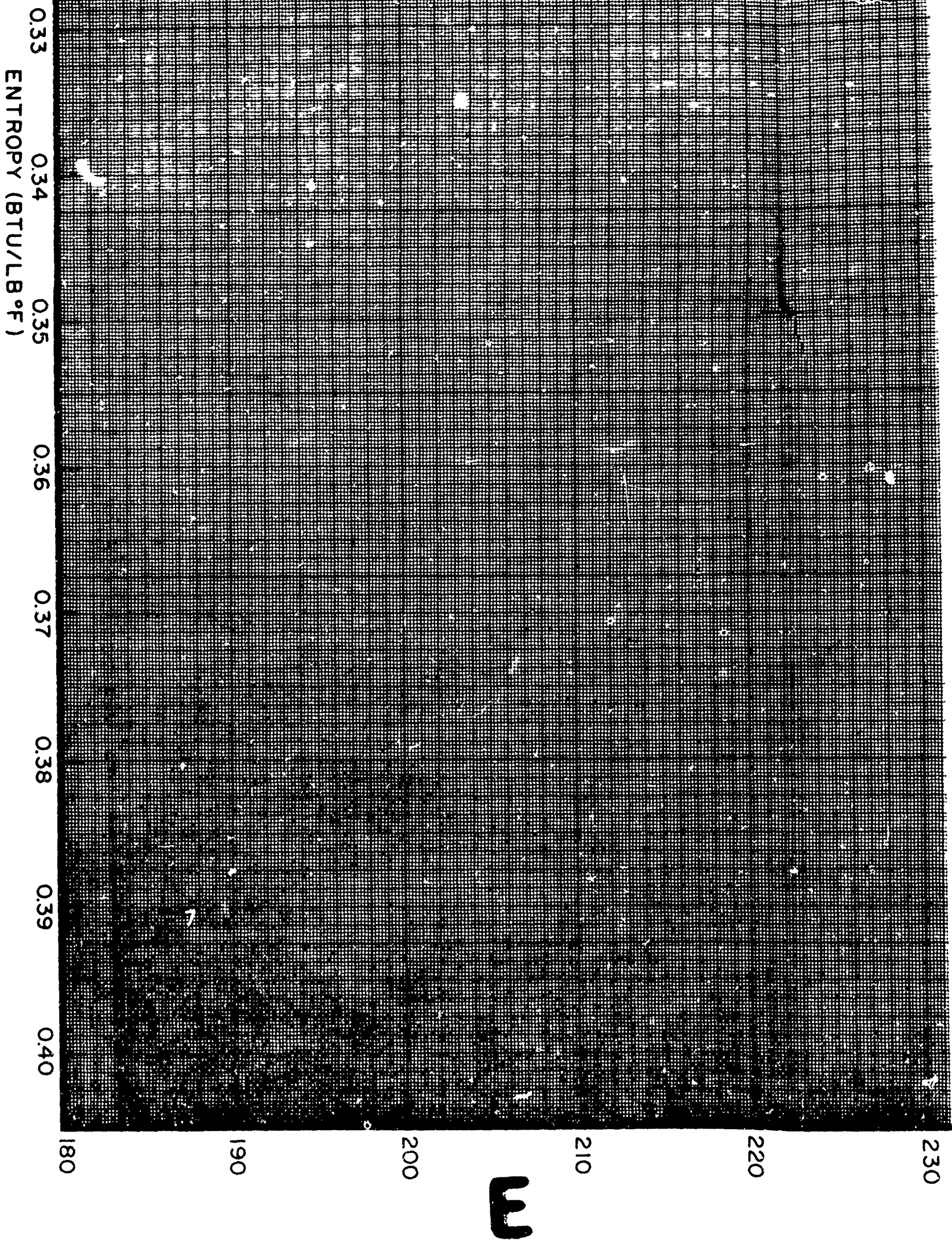
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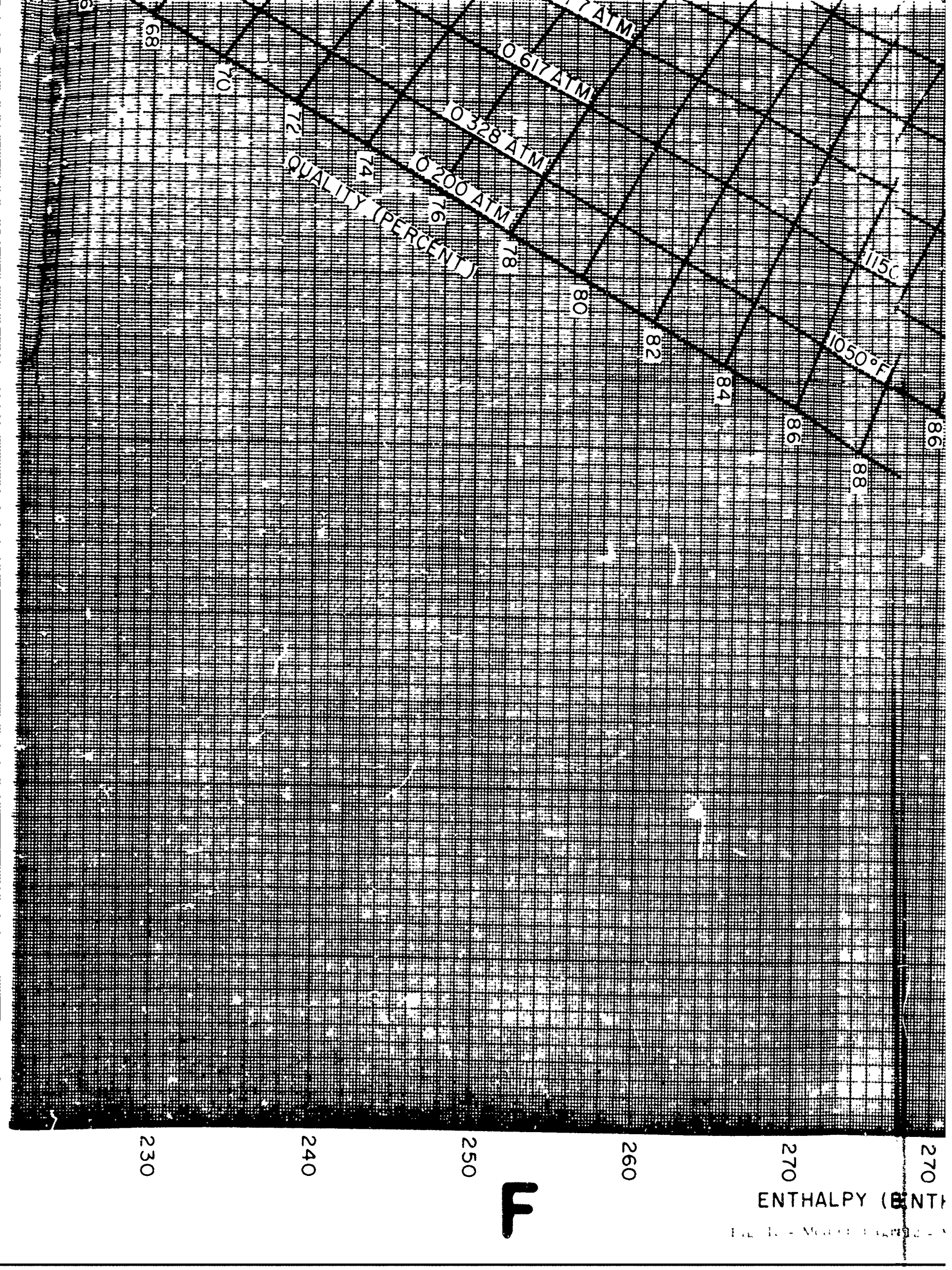
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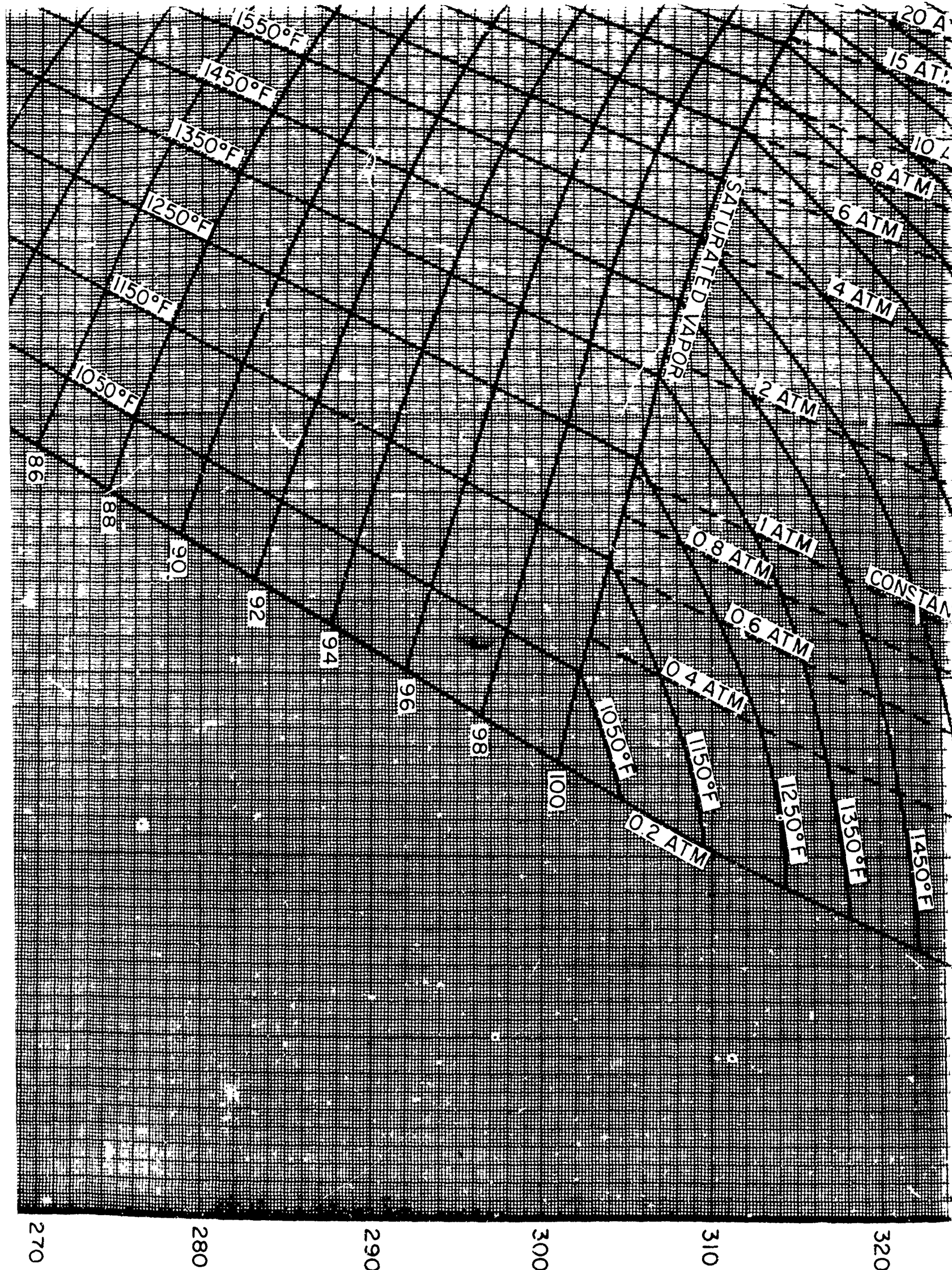
320











ENTHALPY (BTU/LB)

2 - Mollier diagram of water

ENTROPY (BTU/LB-°F)

0.33 0.34 0.35 0.36 0.37 0.38 0.39 0.40

CONSTANT PRESSURE

CONSTANT TEMPERATURE

15 ATM
10 ATM
8 ATM
6 ATM
4 ATM

2550°F

2450°F

2350°F

2250°F

2150°F

2050°F

1950°F

1850°F

1750°F

1650°F

1550°F

1450°F

320 330 340 350 360 370

H

The present study represents the only known PVT measurements of cesium which have been published. Measurements in the intermediate temperature range have been in progress at MSAR (5), and the results should be available for comparison in the near future. There are several publications in which thermodynamic properties of the vapor have been computed from saturation pressures, spectroscopic data, and published thermodynamic functions of the monomeric and dimeric vapors. The properties derived in this report from the PVT study were compared with those computed in two recent publications by Agapova et al. (14) and Weatherford et al. (15). If we arbitrarily take the NRL data as a reference and compare at each temperature enthalpy and entropy changes from p_s to 0.2 atm, enthalpy changes reported by Agapova are 23 to 44% lower, and entropy changes are 9% lower. The enthalpy changes reported by Weatherford are 8 to 41% lower and the entropy changes 4 to 8% lower.

Saturation pressures of cesium were measured between 1215° and 2346°F with the null-point apparatus. The precision and internal consistency of the saturation measurements are attested by the small deviation ($\pm 0.35\%$) of all measured data from a simple three-term equation. In the previous studies on sodium (2) and potassium (1), an equation of the Kirchhoff type was effective in fitting the saturation pressures. This study with cesium reaffirms that an equation of this type is required to describe accurately the dependence of vapor pressure on temperature.

Densities of the condensed phase were measured in the temperature range from 1577° to 2304°F with pycnometers. This method was time consuming, since an independent measurement was required at each temperature, but results of unquestionable accuracy were obtained. With these measurements and those generated in other investigations at lower temperatures, overlapping determinations have been made from the melting point to 2304°F, and the density of liquid cesium is well defined for the full temperature range.

The liquid metal program at this Laboratory is a small part of the national effort in this area. The internal consistency and the confidence limits of the properties of sodium, potassium, and cesium can be more fully evaluated as additional properties are measured for the three metals. Particularly important would be reliable determinations of the heat of vaporization, the specific heat of the liquid and vapor, and the electrical conductivity of the vapor. A good example of this type of evaluation is provided by recent measurements at Aerojet-General Nucleonics (4) of the heats of vaporization of cesium. These were measured directly and have been shown to substantiate those computed in this report from the Clapeyron equation. Similarly, a direct determination of the specific heat of the vapor would test the values computed from the virial equation of state, and a determination of the electrical conductivity would provide additional information on the degree of ionization of the vapor.

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NOMENCLATURE AND UNITS

- B second virial coefficient, cu ft/mole
 C third virial coefficient, (cu ft)²/(mole)²

| | |
|--------------|--|
| D | fourth virial coefficient, $(\text{cu ft})^3/(\text{mole})^3$ |
| E | fifth virial coefficient, $(\text{cu ft})^4/(\text{mole})^4$ |
| c_p | specific heat at constant pressure, $\text{Btu/lb-}^\circ\text{F}$ |
| d | density, lb/cu ft |
| f | free energy, Btu/lb |
| F | free energy, Btu/lb-mole |
| h | enthalpy per unit mass, Btu/lb |
| Δh | enthalpy change per unit mass, Btu/lb |
| Δh_2 | enthalpy change for the formation of a unit mass of dimer from monomer, Btu/lb |
| Δh_v | enthalpy change upon vaporization of a unit mass at equilibrium, Btu/lb |
| H | enthalpy per mole, Btu/lb-mole |
| ΔH | enthalpy change per mole, Btu/lb-mole |
| ΔH_2 | enthalpy change for the formation of one mole of dimer from monomer, Btu/lb-mole |
| ΔH_v | enthalpy change upon vaporization of a mole at equilibrium, Btu/lb-mole |
| J | any unit conversion |
| k | equilibrium constant |
| k'_2 | apparent equilibrium constant assuming only diatomic and monatomic species |
| M | molecular weight |
| p | absolute pressure, atm |
| R | gas constant |
| s | entropy per unit mass, $\text{Btu/lb-}^\circ\text{F}$ |
| Δs_v | entropy change upon vaporization of a unit mass at equilibrium, $\text{Btu/lb-}^\circ\text{F}$ |
| T | absolute temperature, $^\circ\text{R}$ |
| t | temperature, $^\circ\text{F}$ |
| \bar{v} | molal volume (normally per formula weight of monomer), cu ft/lb-mole |
| v | specific volume, cu ft/lb |
| z | compressibility factor, $p\bar{v}/RT$ |

Subscripts

| | |
|-----|--|
| a | quantity for equilibrium molecular mixture |
| v | quantity for the vapor in a state |
| 0 | quantity at 0°R |
| p | constant pressure change |
| s | quantity at saturation |
| t | constant temperature change |
| 1 | quantity for monatomic species |
| 2 | quantity for diatomic species |
| 3 | quantity for triatomic species |
| 4 | quantity for tetratomic species |

Superscripts

| | |
|-----|--|
| g | quantity in gas state |
| l | quantity in liquid state |
| o | standard state, 1 atm for gas |
| $'$ | apparent quantity, when assuming only diatomic and monatomic species |

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APPENDIX A

SATURATION PROPERTIES OF CESIUM

| T | P _s | v _f | v _g | A _f | A _g | A _g | h _f | A _g | s _f |
|---------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 1250.00 | 1.0766 | .01066 | 6.0596 | 94.69 | 210.99 | 305.69 | .2293 | .1234 | .3527 |
| 1275.00 | 1.2249 | .01094 | 7.1572 | 96.20 | 209.65 | 306.06 | .2302 | .1210 | .3511 |
| 1300.00 | 1.3862 | .01101 | 8.3776 | 97.72 | 208.70 | 306.41 | .2310 | .1186 | .3496 |
| 1325.00 | 1.5676 | .01107 | 9.7022 | 99.24 | 207.53 | 306.76 | .2319 | .1163 | .3482 |
| 1350.00 | 1.7641 | .01114 | 5.1146 | 100.76 | 206.34 | 307.10 | .2327 | .1140 | .3467 |
| 1375.00 | 1.9766 | .01121 | 4.6015 | 102.28 | 205.15 | 307.43 | .2336 | .1118 | .3454 |
| 1400.00 | 2.2122 | .01128 | 4.1522 | 103.81 | 203.95 | 307.76 | .2344 | .1097 | .3441 |
| 1425.00 | 2.4657 | .01135 | 3.7574 | 105.34 | 202.74 | 308.08 | .2352 | .1076 | .3428 |
| 1450.00 | 2.7403 | .01142 | 3.4093 | 106.86 | 201.53 | 308.39 | .2360 | .1055 | .3415 |
| 1475.00 | 3.0369 | .01150 | 3.1017 | 108.39 | 200.31 | 308.70 | .2368 | .1035 | .3403 |
| 1500.00 | 3.3565 | .01157 | 2.8289 | 109.91 | 199.10 | 309.01 | .2376 | .1016 | .3392 |
| 1525.00 | 3.7000 | .01165 | 2.5864 | 111.43 | 197.88 | 309.31 | .2383 | .0997 | .3380 |
| 1550.00 | 4.0685 | .01173 | 2.3703 | 112.95 | 196.66 | 309.62 | .2391 | .0979 | .3369 |
| 1575.00 | 4.4629 | .01181 | 2.1771 | 114.47 | 195.45 | 309.92 | .2396 | .0961 | .3359 |
| 1600.00 | 4.8842 | .01189 | 2.0041 | 115.98 | 194.24 | 310.22 | .2406 | .0943 | .3349 |
| 1625.00 | 5.3333 | .01197 | 1.8487 | 117.49 | 193.03 | 310.53 | .2413 | .0926 | .3339 |
| 1650.00 | 5.8111 | .01205 | 1.7089 | 119.00 | 191.83 | 310.83 | .2420 | .0909 | .3329 |
| 1675.00 | 6.3185 | .01213 | 1.5827 | 120.51 | 190.63 | 311.14 | .2427 | .0893 | .3320 |
| 1700.00 | 6.8565 | .01222 | 1.4687 | 122.01 | 189.44 | 311.45 | .2434 | .0877 | .3311 |
| 1725.00 | 7.4256 | .01231 | 1.3654 | 123.51 | 188.26 | 311.77 | .2441 | .0862 | .3302 |
| 1750.00 | 8.0273 | .01240 | 1.2715 | 125.01 | 187.07 | 312.08 | .2447 | .0847 | .3294 |
| 1775.00 | 8.6619 | .01249 | 1.1862 | 126.51 | 185.89 | 312.40 | .2454 | .0832 | .3286 |
| 1800.00 | 9.3302 | .01258 | 1.1083 | 128.02 | 184.71 | 312.73 | .2461 | .0817 | .3278 |
| 1825.00 | 10.0332 | .01268 | 1.0372 | 129.53 | 183.53 | 313.05 | .2467 | .0803 | .3270 |
| 1850.00 | 10.7715 | .01277 | .9721 | 131.05 | 182.33 | 313.36 | .2474 | .0789 | .3263 |
| 1875.00 | 11.5459 | .01287 | .9124 | 132.57 | 181.13 | 313.71 | .2487 | .0776 | .3256 |
| 1900.00 | 12.3570 | .01297 | .8576 | 134.11 | 179.92 | 314.04 | .2493 | .0762 | .3249 |
| 1925.00 | 13.2054 | .01307 | .8070 | 135.66 | 178.70 | 314.36 | .2499 | .0749 | .3242 |
| 1950.00 | 14.0919 | .01317 | .7604 | 137.23 | 177.45 | 314.68 | .2506 | .0736 | .3236 |
| 1975.00 | 15.0170 | .01326 | .7173 | 138.82 | 176.18 | 315.00 | .2512 | .0724 | .3229 |
| 2000.00 | 15.9812 | .01339 | .6774 | 140.43 | 174.88 | 315.31 | .2519 | .0711 | .3223 |
| 2025.00 | 16.9852 | .01350 | .6404 | 142.06 | 173.55 | 315.61 | .2525 | .0698 | .3217 |
| 2050.00 | 18.0294 | .01361 | .6059 | 143.72 | 172.18 | 315.90 | .2532 | .0686 | .3211 |
| 2075.00 | 19.1142 | .01372 | .5739 | 145.40 | 170.77 | 316.17 | .2538 | .0674 | .3205 |
| 2100.00 | 20.2407 | .01384 | .5440 | 147.10 | 169.32 | 316.43 | .2545 | .0661 | .3200 |
| 2125.00 | 21.4077 | .01396 | .5161 | 148.83 | 167.83 | 316.66 | .2551 | .0649 | .3194 |
| 2150.00 | 22.6171 | .01408 | .4900 | 150.58 | 166.29 | 316.87 | .2558 | .0637 | .3189 |
| 2175.00 | 23.8687 | .01420 | .4656 | 152.35 | 164.72 | 317.06 | .2564 | .0625 | .3183 |
| 2200.00 | 25.1630 | .01433 | .4427 | 154.12 | 163.11 | 317.23 | .2569 | .0613 | .3178 |
| 2225.00 | 26.5001 | .01446 | .4213 | 155.88 | 161.49 | 317.37 | .2577 | .0602 | .3172 |
| 2250.00 | 27.8803 | .01459 | .4014 | 157.61 | 159.86 | 317.49 | .2583 | .0590 | .3167 |
| 2275.00 | 29.3039 | .01473 | .3828 | 159.30 | 158.29 | 317.59 | .2589 | .0579 | .3162 |
| 2300.00 | 30.7711 | .01487 | .3655 | 160.97 | 156.77 | 317.68 | .2594 | .0568 | .3157 |
| 2325.00 | 32.2820 | .01501 | .3495 | 162.42 | 155.35 | 317.77 | .2599 | .0558 | .3152 |
| 2350.00 | 33.8367 | .01515 | .3348 | 163.79 | 154.09 | 317.86 | .2599 | .0548 | .3147 |

APPENDIX B
THERMODYNAMIC PROPERTIES OF CESIUM VAPOR

| t | p | c_p^s | z | h^s | s^s | c_p^g |
|---------|--------|---------|--------|--------|--------|---------|
| 1250.00 | 1.0768 | 8.0598 | .92387 | 305.69 | .35270 | .0671 |
| 1250.00 | 1.0000 | 8.7203 | .92917 | 306.40 | .35414 | .0653 |
| 1250.00 | .8000 | 11.0740 | .94310 | 308.28 | .35836 | .0604 |
| 1250.00 | .6000 | 14.9858 | .95718 | 310.19 | .36357 | .0551 |
| 1250.00 | .4000 | 22.8122 | .97138 | 312.13 | .37055 | .0494 |
| 1250.00 | .2000 | 46.2952 | .98566 | 314.09 | .38183 | .0435 |
| 1275.00 | 1.2249 | 7.1572 | .91983 | 306.06 | .35114 | .0679 |
| 1275.00 | 1.0000 | 8.9045 | .93426 | 308.01 | .35507 | .0631 |
| 1275.00 | .8000 | 11.2853 | .94724 | 309.77 | .35923 | .0584 |
| 1275.00 | .6000 | 15.2549 | .96033 | 311.55 | .36436 | .0535 |
| 1275.00 | .4000 | 23.1962 | .97350 | 313.35 | .37126 | .0483 |
| 1275.00 | .2000 | 47.0230 | .98673 | 315.17 | .38246 | .0429 |
| 1300.00 | 1.3882 | 6.3778 | .91574 | 306.41 | .34963 | .0688 |
| 1300.00 | 1.0000 | 9.0778 | .93890 | 309.56 | .35596 | .0610 |
| 1300.00 | .8000 | 11.4933 | .95100 | 311.20 | .36005 | .0566 |
| 1300.00 | .6000 | 15.5206 | .96317 | 312.87 | .36511 | .0520 |
| 1300.00 | .4000 | 23.5767 | .97541 | 314.54 | .37194 | .0473 |
| 1300.00 | .2000 | 47.7471 | .98769 | 316.23 | .38307 | .0424 |
| 1325.00 | 1.5676 | 5.7022 | .91160 | 306.76 | .34816 | .0696 |
| 1325.00 | 1.0000 | 9.2482 | .94313 | 311.06 | .35681 | .0590 |
| 1325.00 | .8000 | 11.6985 | .95441 | 312.60 | .36084 | .0549 |
| 1325.00 | .6000 | 15.7833 | .96575 | 314.15 | .36583 | .0507 |
| 1325.00 | .4000 | 23.9340 | .97714 | 315.71 | .37260 | .0463 |
| 1325.00 | .2000 | 48.4680 | .98856 | 317.28 | .38367 | .0419 |
| 1350.00 | 1.7641 | 5.1146 | .90742 | 307.10 | .34675 | .0703 |
| 1350.00 | 1.0000 | 9.4160 | .94698 | 312.51 | .35761 | .0572 |
| 1350.00 | .8000 | 11.9009 | .95751 | 313.95 | .36159 | .0534 |
| 1350.00 | .6000 | 16.0432 | .96809 | 315.40 | .36653 | .0495 |
| 1350.00 | .4000 | 24.3286 | .97870 | 316.86 | .37324 | .0455 |
| 1350.00 | .2000 | 49.1860 | .98934 | 318.33 | .38425 | .0415 |
| 1375.00 | 1.9786 | 4.6015 | .90319 | 307.43 | .34538 | .0710 |
| 1375.00 | 1.0000 | 9.5815 | .95050 | 313.92 | .35839 | .0555 |
| 1375.00 | .8000 | 12.1009 | .96034 | 315.27 | .36231 | .0520 |
| 1375.00 | .6000 | 16.3005 | .97022 | 316.63 | .36720 | .0484 |
| 1375.00 | .4000 | 24.7005 | .98013 | 317.99 | .37386 | .0448 |
| 1375.00 | .2000 | 49.9015 | .99006 | 319.36 | .38481 | .0411 |
| 1400.00 | 2.2122 | 4.1522 | .89895 | 307.76 | .34405 | .0717 |
| 1400.00 | 2.0000 | 4.6407 | .90835 | 309.05 | .34611 | .0689 |
| 1400.00 | 1.0000 | 9.7448 | .95370 | 315.29 | .35913 | .0540 |
| 1400.00 | .8000 | 12.2927 | .96291 | 316.55 | .36301 | .0508 |
| 1400.00 | .6000 | 16.5556 | .97216 | 317.83 | .36785 | .0475 |
| 1400.00 | .4000 | 25.0702 | .98142 | 319.10 | .37446 | .0441 |
| 1400.00 | .2000 | 50.6146 | .99070 | 320.38 | .38537 | .0408 |
| 1425.00 | 2.4657 | 3.7574 | .89468 | 308.08 | .34277 | .0724 |
| 1425.00 | 2.0000 | 4.7325 | .91402 | 310.74 | .34701 | .0666 |
| 1425.00 | 1.0000 | 9.9061 | .95663 | 316.62 | .35984 | .0528 |
| 1425.00 | .8000 | 12.4944 | .96526 | 317.81 | .36368 | .0496 |
| 1425.00 | .6000 | 16.8087 | .97392 | 319.00 | .36848 | .0466 |
| 1425.00 | .4000 | 25.4377 | .98260 | 320.20 | .37504 | .0435 |
| 1425.00 | .2000 | 51.3256 | .99130 | 321.40 | .38591 | .0405 |
| 1450.00 | 2.7403 | 3.4093 | .89040 | 308.39 | .34152 | .0730 |
| 1450.00 | 2.0000 | 4.8227 | .91925 | 312.38 | .34787 | .0645 |
| 1450.00 | 1.0000 | 10.0656 | .95931 | 317.92 | .36053 | .0514 |
| 1450.00 | .8000 | 12.6883 | .96741 | 319.04 | .36432 | .0486 |
| 1450.00 | .6000 | 17.0599 | .97534 | 320.16 | .36909 | .0458 |
| 1450.00 | .4000 | 25.8034 | .98368 | 321.28 | .37561 | .0430 |
| 1450.00 | .2000 | 52.0347 | .99184 | 322.40 | .38644 | .0402 |
| 1475.00 | 3.0369 | 3.1011 | .88612 | 308.70 | .34032 | .0735 |
| 1475.00 | 3.0000 | 3.1445 | .88745 | 308.89 | .34058 | .0732 |
| 1475.00 | 2.0000 | 4.9114 | .92407 | 313.97 | .34870 | .0624 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| t | p | v^g | z | h^g | s^g | c_p^g |
|---------|--------|---------|--------|--------|--------|---------|
| 1475.00 | 1.0000 | 10.2235 | .96176 | 319.19 | .34119 | .0502 |
| 1475.00 | .8000 | 12.8806 | .96938 | 320.24 | .36495 | .0477 |
| 1475.00 | .6000 | 17.3094 | .97702 | 321.29 | .36968 | .0451 |
| 1475.00 | .4000 | 26.1674 | .98467 | 322.35 | .37617 | .0425 |
| 1475.00 | .2000 | 52.7421 | .99233 | 323.41 | .38696 | .0400 |
| 1500.00 | 3.3565 | 2.8289 | .88185 | 309.01 | .33916 | .0740 |
| 1500.00 | 3.0000 | 3.2082 | .89388 | 310.69 | .34150 | .0708 |
| 1500.00 | 2.0000 | 4.9987 | .92850 | 315.50 | .34949 | .0605 |
| 1500.00 | 1.0000 | 10.3799 | .96401 | 320.43 | .36182 | .0492 |
| 1500.00 | .8000 | 13.0713 | .97118 | 321.42 | .36556 | .0468 |
| 1500.00 | .6000 | 17.5574 | .97837 | 322.41 | .37026 | .0445 |
| 1500.00 | .4000 | 26.5299 | .98557 | 323.41 | .37671 | .0421 |
| 1500.00 | .2000 | 53.4480 | .99278 | 324.40 | .38747 | .0397 |
| 1525.00 | 3.7000 | 2.5864 | .87759 | 309.31 | .33803 | .0745 |
| 1525.00 | 3.0000 | 3.2708 | .89984 | 312.43 | .34238 | .0685 |
| 1525.00 | 2.0000 | 5.0848 | .93259 | 317.00 | .35024 | .0588 |
| 1525.00 | 1.0000 | 10.5348 | .96608 | 321.65 | .36244 | .0483 |
| 1525.00 | .8000 | 13.2607 | .97284 | 322.58 | .36615 | .0461 |
| 1525.00 | .6000 | 17.8040 | .97962 | 323.52 | .37082 | .0439 |
| 1525.00 | .4000 | 26.8910 | .98640 | 324.46 | .37725 | .0417 |
| 1525.00 | .2000 | 54.1525 | .99320 | 325.39 | .38797 | .0396 |
| 1550.00 | 4.0685 | 2.3703 | .87335 | 309.62 | .33694 | .0749 |
| 1550.00 | 4.0000 | 2.4165 | .87536 | 309.90 | .33730 | .0744 |
| 1550.00 | 3.0000 | 3.3324 | .90537 | 314.11 | .34323 | .0664 |
| 1550.00 | 2.0000 | 5.1697 | .93636 | 318.45 | .35097 | .0572 |
| 1550.00 | 1.0000 | 10.6886 | .96799 | 322.84 | .36304 | .0474 |
| 1550.00 | .8000 | 13.4488 | .97437 | 323.73 | .36672 | .0454 |
| 1550.00 | .6000 | 18.0493 | .98076 | 324.61 | .37136 | .0434 |
| 1550.00 | .4000 | 27.2508 | .98716 | 325.50 | .37777 | .0414 |
| 1550.00 | .2000 | 54.8557 | .99358 | 326.38 | .38847 | .0394 |
| 1575.00 | 4.4629 | 2.1771 | .86914 | 309.92 | .33588 | .0753 |
| 1575.00 | 4.0000 | 2.4650 | .88198 | 311.73 | .33821 | .0721 |
| 1575.00 | 3.0000 | 3.3929 | .91050 | 315.75 | .34404 | .0644 |
| 1575.00 | 2.0000 | 5.2534 | .93984 | 319.86 | .35167 | .0557 |
| 1575.00 | 1.0000 | 10.8412 | .96975 | 324.02 | .36362 | .0466 |
| 1575.00 | .8000 | 13.6357 | .97578 | 324.85 | .36728 | .0448 |
| 1575.00 | .6000 | 18.2935 | .98182 | 325.69 | .37190 | .0429 |
| 1575.00 | .4000 | 27.6095 | .98787 | 326.53 | .37828 | .0411 |
| 1575.00 | .2000 | 55.5577 | .99393 | 327.36 | .38895 | .0392 |
| 1600.00 | 4.8842 | 2.0041 | .86496 | 310.22 | .33486 | .0756 |
| 1600.00 | 4.0000 | 2.5127 | .88814 | 313.51 | .33907 | .0699 |
| 1600.00 | 3.0000 | 3.4526 | .91525 | 317.33 | .34481 | .0625 |
| 1600.00 | 2.0000 | 5.3362 | .94306 | 321.23 | .35234 | .0544 |
| 1600.00 | 1.0000 | 10.9928 | .97137 | 325.18 | .36419 | .0459 |
| 1600.00 | .8000 | 13.8216 | .97707 | 325.97 | .36782 | .0442 |
| 1600.00 | .6000 | 18.5367 | .98279 | 326.76 | .37242 | .0425 |
| 1600.00 | .4000 | 27.9671 | .98852 | 327.55 | .37878 | .0408 |
| 1600.00 | .2000 | 56.2587 | .99425 | 328.34 | .38943 | .0391 |
| 1625.00 | 5.3333 | 1.8487 | .86032 | 310.53 | .33388 | .0759 |
| 1625.00 | 5.0000 | 1.9906 | .86892 | 311.68 | .33526 | .0741 |
| 1625.00 | 4.0000 | 2.5597 | .89389 | 315.23 | .33991 | .0678 |
| 1625.00 | 3.0000 | 3.5113 | .91966 | 318.87 | .34555 | .0607 |
| 1625.00 | 2.0000 | 5.4181 | .94604 | 322.58 | .35299 | .0532 |
| 1625.00 | 1.0000 | 11.1434 | .97287 | 326.32 | .36474 | .0453 |
| 1625.00 | .8000 | 14.0066 | .97827 | 327.07 | .36835 | .0437 |
| 1625.00 | .6000 | 18.7789 | .98369 | 327.82 | .37293 | .0421 |
| 1625.00 | .4000 | 28.3237 | .98912 | 328.57 | .37927 | .0405 |
| 1625.00 | .2000 | 56.9588 | .99456 | 329.32 | .38990 | .0390 |
| 1650.00 | 5.8111 | 1.7089 | .85672 | 310.83 | .33292 | .0761 |
| 1650.00 | 5.0000 | 2.0295 | .87542 | 313.50 | .33613 | .0719 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| t | p | v^g | z | h^g | s^g | c_p^g |
|---------|--------|---------|--------|--------|--------|---------|
| 1650.00 | 4.0000 | 2.60 | .89924 | 316.90 | .34070 | .0658 |
| 1650.00 | 3.0000 | 3.5692 | .92376 | 320.37 | .34627 | .0591 |
| 1650.00 | 2.0000 | 5.4990 | .94881 | 323.89 | .35362 | .0520 |
| 1650.00 | 1.0000 | 11.2931 | .97426 | 327.44 | .36527 | .0447 |
| 1650.00 | .8000 | 14.1907 | .97939 | 328.15 | .36887 | .0433 |
| 1650.00 | .6000 | 19.0202 | .98453 | 328.87 | .37343 | .0418 |
| 1650.00 | .4000 | 28.6795 | .98967 | 329.58 | .37975 | .0403 |
| 1650.00 | .2000 | 57.6580 | .99483 | 330.29 | .39037 | .0388 |
| 1675.00 | 6.3185 | 1.5827 | .85265 | 311.14 | .33200 | .0763 |
| 1675.00 | 6.0000 | 1.6801 | .85949 | 312.12 | .33312 | .0749 |
| 1675.00 | 5.0000 | 2.0678 | .88150 | 315.28 | .33697 | .0698 |
| 1675.00 | 4.0000 | 2.6514 | .90423 | 318.52 | .34147 | .0640 |
| 1675.00 | 3.0000 | 3.6264 | .92757 | 321.83 | .34696 | .0576 |
| 1675.00 | 2.0000 | 5.5792 | .95137 | 325.18 | .35422 | .0510 |
| 1675.00 | 1.0000 | 11.4420 | .97555 | 328.55 | .36580 | .0442 |
| 1675.00 | .8000 | 14.3740 | .98042 | 329.23 | .36938 | .0428 |
| 1675.00 | .6000 | 19.2607 | .98530 | 329.91 | .37392 | .0415 |
| 1675.00 | .4000 | 29.0345 | .99019 | 330.58 | .38022 | .0401 |
| 1675.00 | .2000 | 58.3563 | .99509 | 331.26 | .39082 | .0387 |
| 1700.00 | 6.8565 | 1.4687 | .84863 | 311.45 | .33110 | .0765 |
| 1700.00 | 6.0000 | 1.7129 | .86611 | 313.97 | .33398 | .0728 |
| 1700.00 | 5.0000 | 2.1055 | .88719 | 316.99 | .33777 | .0678 |
| 1700.00 | 4.0000 | 2.6963 | .90889 | 320.10 | .34220 | .0622 |
| 1700.00 | 3.0000 | 3.6829 | .93111 | 323.25 | .34762 | .0563 |
| 1700.00 | 2.0000 | 5.6587 | .95375 | 326.44 | .35481 | .0501 |
| 1700.00 | 1.0000 | 11.5902 | .97674 | 329.65 | .36631 | .0437 |
| 1700.00 | .8000 | 14.5565 | .98137 | 330.30 | .36987 | .0425 |
| 1700.00 | .6000 | 19.5005 | .98602 | 330.94 | .37440 | .0412 |
| 1700.00 | .4000 | 29.3887 | .99067 | 331.58 | .38069 | .0399 |
| 1700.00 | .2000 | 59.0540 | .99533 | 332.23 | .39127 | .0386 |
| 1725.00 | 7.4258 | 1.3654 | .84465 | 311.77 | .33024 | .0766 |
| 1725.00 | 7.0000 | 1.4623 | .85277 | 312.94 | .33152 | .0750 |
| 1725.00 | 6.0000 | 1.7452 | .87233 | 315.76 | .33480 | .0708 |
| 1725.00 | 5.0000 | 2.1427 | .89251 | 318.67 | .33854 | .0659 |
| 1725.00 | 4.0000 | 2.7405 | .91323 | 321.63 | .34291 | .0606 |
| 1725.00 | 3.0000 | 3.7387 | .93441 | 324.64 | .34825 | .0550 |
| 1725.00 | 2.0000 | 5.7375 | .95597 | 327.68 | .35538 | .0492 |
| 1725.00 | 1.0000 | 11.7377 | .97786 | 330.74 | .36681 | .0433 |
| 1725.00 | .8000 | 14.7384 | .98227 | 331.35 | .37036 | .0421 |
| 1725.00 | .6000 | 19.7396 | .98669 | 331.97 | .37487 | .0409 |
| 1725.00 | .4000 | 29.7423 | .99111 | 332.58 | .38115 | .0397 |
| 1725.00 | .2000 | 59.7509 | .99555 | 333.19 | .39172 | .0386 |
| 1750.00 | 8.0273 | 1.2715 | .84071 | 312.08 | .32940 | .0766 |
| 1750.00 | 8.0000 | 1.2766 | .84120 | 312.15 | .32948 | .0765 |
| 1750.00 | 7.0000 | 1.4905 | .85939 | 314.79 | .33236 | .0730 |
| 1750.00 | 6.0000 | 1.7770 | .87817 | 317.51 | .33560 | .0688 |
| 1750.00 | 5.0000 | 2.1793 | .89749 | 320.29 | .33928 | .0641 |
| 1750.00 | 4.0000 | 2.7842 | .91728 | 323.13 | .34359 | .0591 |
| 1750.00 | 3.0000 | 3.7940 | .93748 | 326.00 | .34888 | .0538 |
| 1750.00 | 2.0000 | 5.8157 | .95804 | 328.90 | .35594 | .0484 |
| 1750.00 | 1.0000 | 11.8846 | .97889 | 331.82 | .36730 | .0429 |
| 1750.00 | .8000 | 14.9196 | .98309 | 332.40 | .37084 | .0418 |
| 1750.00 | .6000 | 19.9780 | .98731 | 332.99 | .37534 | .0407 |
| 1750.00 | .4000 | 30.0952 | .99153 | 333.57 | .38160 | .0396 |
| 1750.00 | .2000 | 60.4472 | .99576 | 334.15 | .39216 | .0385 |
| 1775.00 | 8.6619 | 1.1862 | .83679 | 312.40 | .32859 | .0766 |
| 1775.00 | 8.0000 | 1.3016 | .84810 | 314.04 | .33033 | .0746 |
| 1775.00 | 7.0000 | 1.5183 | .86563 | 316.59 | .33318 | .0710 |
| 1775.00 | 6.0000 | 1.8083 | .88366 | 319.20 | .33636 | .0670 |
| 1775.00 | 5.0000 | 2.2154 | .90216 | 321.87 | .33999 | .0625 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| t | p | v^g | z | h^g | s^g | c_p^g |
|---------|---------|---------|--------|--------|--------|---------|
| 1775.00 | 4.0000 | 2.8273 | .92107 | 324.59 | .34424 | .0577 |
| 1775.00 | 3.0000 | 3.8486 | .94039 | 327.33 | .34948 | .0528 |
| 1775.00 | 2.0000 | 5.8933 | .95996 | 330.10 | .35648 | .0477 |
| 1775.00 | 1.0000 | 12.0310 | .97986 | 332.88 | .36778 | .0425 |
| 1775.00 | .8000 | 15.1003 | .98387 | 333.44 | .37130 | .0415 |
| 1775.00 | .6000 | 20.2159 | .98789 | 334.00 | .37579 | .0405 |
| 1775.00 | .4000 | 30.4476 | .99192 | 334.56 | .38204 | .0394 |
| 1775.00 | .2000 | 61.1430 | .99599 | 335.11 | .39259 | .0384 |
| 1800.00 | 9.3302 | 1.1083 | .83290 | 312.73 | .32781 | .0766 |
| 1800.00 | 9.0000 | 1.1563 | .83822 | 313.50 | .32860 | .0757 |
| 1800.00 | 8.0000 | 1.3263 | .85463 | 315.88 | .33115 | .0727 |
| 1800.00 | 7.0000 | 1.5458 | .87150 | 318.34 | .33395 | .0692 |
| 1800.00 | 6.0000 | 1.8392 | .88881 | 320.85 | .33710 | .0652 |
| 1800.00 | 5.0000 | 2.2510 | .90693 | 323.42 | .34068 | .0609 |
| 1800.00 | 4.0000 | 2.8699 | .92461 | 326.01 | .34488 | .0564 |
| 1800.00 | 3.0000 | 3.9028 | .94303 | 328.64 | .35006 | .0518 |
| 1800.00 | 2.0000 | 5.9704 | .96176 | 331.29 | .35700 | .0470 |
| 1800.00 | 1.0000 | 12.1768 | .98078 | 333.94 | .36825 | .0422 |
| 1800.00 | .8000 | 15.2804 | .98459 | 334.48 | .37176 | .0412 |
| 1800.00 | .6000 | 20.4533 | .98843 | 335.01 | .37624 | .0403 |
| 1800.00 | .4000 | 30.7994 | .99228 | 335.54 | .38248 | .0393 |
| 1800.00 | .2000 | 61.8382 | .99613 | 336.07 | .39302 | .0383 |
| 1825.00 | 10.0332 | 1.0372 | .82903 | 313.05 | .32705 | .0766 |
| 1825.00 | 10.0000 | 1.0413 | .82953 | 313.13 | .32712 | .0765 |
| 1825.00 | 9.0000 | 1.1785 | .84496 | 315.37 | .32942 | .0739 |
| 1825.00 | 8.0000 | 1.3507 | .86080 | 317.68 | .33194 | .0709 |
| 1825.00 | 7.0000 | 1.5728 | .87704 | 320.05 | .33471 | .0674 |
| 1825.00 | 6.0000 | 1.8697 | .89369 | 322.46 | .33780 | .0636 |
| 1825.00 | 5.0000 | 2.2862 | .91062 | 324.92 | .34134 | .0595 |
| 1825.00 | 4.0000 | 2.9121 | .92793 | 327.41 | .34549 | .0552 |
| 1825.00 | 3.0000 | 3.9565 | .94554 | 329.92 | .35062 | .0509 |
| 1825.00 | 2.0000 | 6.0470 | .96344 | 332.45 | .35752 | .0464 |
| 1825.00 | 1.0000 | 12.3221 | .98160 | 334.99 | .36871 | .0419 |
| 1825.00 | .8000 | 15.4600 | .98526 | 335.50 | .37222 | .0410 |
| 1825.00 | .6000 | 20.6962 | .98893 | 336.01 | .37668 | .0401 |
| 1825.00 | .4000 | 31.1507 | .99261 | 336.52 | .38291 | .0392 |
| 1825.00 | .2000 | 62.5330 | .99630 | 337.03 | .39344 | .0383 |
| 1850.00 | 10.7715 | .9721 | .82519 | 313.38 | .32631 | .0765 |
| 1850.00 | 10.0000 | 1.0615 | .83643 | 315.02 | .32795 | .0748 |
| 1850.00 | 9.0000 | 1.2005 | .85136 | 317.19 | .33022 | .0721 |
| 1850.00 | 8.0000 | 1.3747 | .86664 | 319.43 | .33270 | .0691 |
| 1850.00 | 7.0000 | 1.5994 | .88225 | 321.71 | .33543 | .0657 |
| 1850.00 | 6.0000 | 1.8997 | .89820 | 324.03 | .33849 | .0620 |
| 1850.00 | 5.0000 | 2.3210 | .91446 | 326.39 | .34198 | .0582 |
| 1850.00 | 4.0000 | 2.9538 | .93103 | 328.78 | .34609 | .0541 |
| 1850.00 | 3.0000 | 4.0097 | .94789 | 331.18 | .35117 | .0500 |
| 1850.00 | 2.0000 | 6.1232 | .96501 | 333.61 | .35802 | .0458 |
| 1850.00 | 1.0000 | 12.4669 | .98239 | 336.04 | .36917 | .0416 |
| 1850.00 | .8000 | 15.6392 | .98590 | 336.53 | .37266 | .0408 |
| 1850.00 | .6000 | 20.9266 | .98941 | 337.01 | .37712 | .0399 |
| 1850.00 | .4000 | 31.5016 | .99293 | 337.50 | .38334 | .0391 |
| 1850.00 | .2000 | 63.2272 | .99646 | 337.99 | .39385 | .0382 |
| 1875.00 | 11.5459 | .9124 | .82126 | 313.71 | .32560 | .0764 |
| 1875.00 | 11.0000 | .9666 | .82886 | 314.81 | .32667 | .0753 |
| 1875.00 | 10.0000 | 1.0814 | .84299 | 316.86 | .32874 | .0730 |
| 1875.00 | 9.0000 | 1.2221 | .85742 | 318.97 | .33098 | .0704 |
| 1875.00 | 8.0000 | 1.3985 | .87214 | 321.13 | .33343 | .0674 |
| 1875.00 | 7.0000 | 1.6258 | .88716 | 323.33 | .33613 | .0641 |
| 1875.00 | 6.0000 | 1.9294 | .90247 | 325.57 | .33915 | .0606 |
| 1875.00 | 5.0000 | 2.3553 | .91807 | 327.83 | .34260 | .0569 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| T | P | ρ | γ | α | β | δ |
|---------|---------|---------|----------|----------|---------|----------|
| 1975.00 | 4.0000 | 2.9951 | .93394 | 330.12 | .34667 | .0531 |
| 1975.00 | 3.0000 | 4.3625 | .95059 | 332.42 | .35171 | .0492 |
| 1975.00 | 2.0000 | 6.1989 | .96649 | 334.74 | .35851 | .0453 |
| 1975.00 | 1.0000 | 12.6113 | .98313 | 337.07 | .36962 | .0413 |
| 1975.00 | .8000 | 15.9100 | .98649 | 337.54 | .37310 | .0405 |
| 1975.00 | .6000 | 21.1626 | .98989 | 338.01 | .37755 | .0396 |
| 1975.00 | .4000 | 31.8521 | .99323 | 338.48 | .38376 | .0390 |
| 1975.00 | .2000 | 65.9211 | .99661 | 338.94 | .39427 | .0382 |
| 1900.00 | 12.3570 | .9576 | .81734 | 314.04 | .32491 | .0763 |
| 1900.00 | 12.0000 | .8882 | .82209 | 314.72 | .32556 | .0757 |
| 1900.00 | 11.5000 | .9948 | .83554 | 316.67 | .32746 | .0737 |
| 1900.00 | 10.0000 | 1.1010 | .84723 | 318.67 | .32951 | .0713 |
| 1900.00 | 9.0000 | 1.2434 | .86316 | 320.71 | .33172 | .0697 |
| 1900.00 | 8.0000 | 1.4219 | .87734 | 322.80 | .33414 | .0657 |
| 1900.00 | 7.0000 | 1.6517 | .89179 | 324.91 | .33680 | .0626 |
| 1900.00 | 6.0000 | 1.9588 | .90649 | 327.06 | .33979 | .0592 |
| 1900.00 | 5.0000 | 2.3893 | .92146 | 329.24 | .34320 | .0558 |
| 1900.00 | 4.0000 | 3.0360 | .93668 | 331.43 | .34723 | .0522 |
| 1900.00 | 3.0000 | 4.1146 | .95215 | 333.65 | .35223 | .0485 |
| 1900.00 | 2.0000 | 6.2743 | .96787 | 335.87 | .35899 | .0446 |
| 1900.00 | 1.0000 | 12.7554 | .98383 | 338.11 | .37005 | .0411 |
| 1900.00 | .8000 | 15.9964 | .98704 | 338.55 | .37353 | .0404 |
| 1900.00 | .6000 | 21.3982 | .99027 | 339.00 | .37797 | .0396 |
| 1900.00 | .4000 | 32.2022 | .99350 | 339.45 | .38417 | .0389 |
| 1900.00 | .2000 | 64.6146 | .99675 | 339.90 | .39467 | .0381 |
| 1975.00 | 13.2054 | .8070 | .81338 | 314.36 | .32424 | .0761 |
| 1925.00 | 13.0000 | .8224 | .81601 | 314.74 | .32459 | .0758 |
| 1925.00 | 12.0000 | .9050 | .82887 | 316.59 | .32635 | .0741 |
| 1925.00 | 11.0000 | 1.0028 | .84191 | 318.49 | .32823 | .0720 |
| 1925.00 | 10.0000 | 1.1265 | .85515 | 320.43 | .33025 | .0697 |
| 1925.00 | 9.0000 | 1.2645 | .86859 | 322.41 | .33244 | .0670 |
| 1925.00 | 8.0000 | 1.4450 | .88225 | 324.42 | .33482 | .0642 |
| 1925.00 | 7.0000 | 1.6774 | .89614 | 326.46 | .33745 | .0612 |
| 1925.00 | 6.0000 | 1.9578 | .91027 | 328.53 | .34040 | .0580 |
| 1925.00 | 5.0000 | 2.4230 | .92464 | 330.62 | .34378 | .0547 |
| 1925.00 | 4.0000 | 3.0766 | .93925 | 332.73 | .34777 | .0513 |
| 1925.00 | 3.0000 | 4.1670 | .95409 | 334.85 | .35273 | .0479 |
| 1925.00 | 2.0000 | 6.3493 | .96917 | 336.99 | .35946 | .0444 |
| 1925.00 | 1.0000 | 12.8991 | .98448 | 339.13 | .37049 | .0409 |
| 1925.00 | .8000 | 16.1744 | .98756 | 339.56 | .37395 | .0402 |
| 1925.00 | .6000 | 21.6335 | .99066 | 339.99 | .37839 | .0395 |
| 1925.00 | .4000 | 32.5519 | .99377 | 340.42 | .38458 | .0388 |
| 1925.00 | .2000 | 65.3077 | .99688 | 340.85 | .39507 | .0381 |
| 1950.00 | 14.6919 | .7604 | .80936 | 314.68 | .32358 | .0760 |
| 1950.00 | 14.0000 | .7665 | .81049 | 314.85 | .32373 | .0759 |
| 1950.00 | 13.0000 | .8380 | .82286 | 316.61 | .32537 | .0744 |
| 1950.00 | 12.0000 | .9217 | .83535 | 318.42 | .32711 | .0725 |
| 1950.00 | 11.0000 | 1.0206 | .84797 | 320.27 | .32997 | .0704 |
| 1950.00 | 10.0000 | 1.1396 | .86111 | 322.15 | .33307 | .0681 |
| 1950.00 | 9.0000 | 1.2953 | .87431 | 324.06 | .33633 | .0655 |
| 1950.00 | 8.0000 | 1.4678 | .88699 | 326.01 | .33949 | .0627 |
| 1950.00 | 7.0000 | 1.7027 | .90025 | 327.97 | .33809 | .0598 |
| 1950.00 | 6.0000 | 2.0165 | .91383 | 329.96 | .34100 | .0568 |
| 1950.00 | 5.0000 | 2.4563 | .92744 | 331.97 | .34434 | .0537 |
| 1950.00 | 4.0000 | 3.1169 | .94166 | 334.00 | .34830 | .0505 |
| 1950.00 | 3.0000 | 4.2187 | .95592 | 336.04 | .35323 | .0472 |
| 1950.00 | 2.0000 | 6.4239 | .97039 | 338.09 | .35992 | .0440 |
| 1950.00 | 1.0000 | 13.0424 | .98509 | 340.15 | .37091 | .0407 |
| 1950.00 | .8000 | 16.3521 | .98806 | 340.56 | .37437 | .0400 |
| 1950.00 | .6000 | 21.8694 | .99103 | 340.97 | .37880 | .0394 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| T | P | ρ | μ | h^0 | s^0 | c_p^0 |
|---------|---------|---------|--------|--------|--------|---------|
| 1950.00 | .4000 | 32.2013 | .99401 | 341.39 | .38498 | .0397 |
| 1950.00 | .2000 | 66.3005 | .99700 | 341.80 | .39547 | .0380 |
| 1975.00 | 15.0170 | .7173 | .80526 | 315.00 | .32295 | .0759 |
| 1975.00 | 15.0000 | .7163 | .80546 | 315.03 | .32297 | .0759 |
| 1975.00 | 14.0000 | .7810 | .81740 | 316.73 | .32451 | .0745 |
| 1975.00 | 13.0000 | .8535 | .82942 | 318.46 | .32613 | .0729 |
| 1975.00 | 12.0000 | .9361 | .84192 | 320.22 | .32785 | .0710 |
| 1975.00 | 11.0000 | 1.0382 | .85373 | 322.01 | .32969 | .0688 |
| 1975.00 | 10.0000 | 1.1586 | .86609 | 323.83 | .33167 | .0665 |
| 1975.00 | 9.0000 | 1.3059 | .87859 | 325.58 | .33380 | .0640 |
| 1975.00 | 8.0000 | 1.4903 | .89127 | 327.55 | .33613 | .0614 |
| 1975.00 | 7.0000 | 1.7278 | .90413 | 329.45 | .33870 | .0586 |
| 1975.00 | 6.0000 | 2.0449 | .91719 | 331.37 | .34158 | .0557 |
| 1975.00 | 5.0000 | 2.4894 | .93046 | 333.30 | .34489 | .0528 |
| 1975.00 | 4.0000 | 3.1568 | .94394 | 335.25 | .34882 | .0497 |
| 1975.00 | 3.0000 | 4.2701 | .95763 | 337.21 | .35371 | .0467 |
| 1975.00 | 2.0000 | 6.4982 | .97194 | 339.18 | .36037 | .0436 |
| 1975.00 | 1.0000 | 13.1854 | .98567 | 341.16 | .37133 | .0405 |
| 1975.00 | .8000 | 16.5294 | .98852 | 341.56 | .37479 | .0399 |
| 1975.00 | .6000 | 22.1030 | .99138 | 341.96 | .37920 | .0393 |
| 1975.00 | .4000 | 33.2503 | .99424 | 342.35 | .38538 | .0386 |
| 1975.00 | .2000 | 66.6929 | .99712 | 342.75 | .39586 | .0380 |
| 2000.00 | 15.9812 | .6774 | .80109 | 315.31 | .32233 | .0758 |
| 2000.00 | 15.0000 | .7320 | .81244 | 316.91 | .32374 | .0746 |
| 2000.00 | 14.0000 | .7955 | .82403 | 318.57 | .32526 | .0731 |
| 2000.00 | 13.0000 | .8688 | .83588 | 320.26 | .32687 | .0714 |
| 2000.00 | 12.0000 | .9543 | .84740 | 321.97 | .32857 | .0694 |
| 2000.00 | 11.0000 | 1.0556 | .85921 | 323.71 | .33039 | .0673 |
| 2000.00 | 10.0000 | 1.1773 | .87113 | 325.48 | .33234 | .0650 |
| 2000.00 | 9.0000 | 1.3262 | .88319 | 327.27 | .33445 | .0626 |
| 2000.00 | 8.0000 | 1.5126 | .89541 | 329.07 | .33675 | .0601 |
| 2000.00 | 7.0000 | 1.7526 | .90779 | 330.90 | .33929 | .0574 |
| 2000.00 | 6.0000 | 2.0730 | .92036 | 332.75 | .34215 | .0547 |
| 2000.00 | 5.0000 | 2.5221 | .93312 | 334.61 | .34543 | .0519 |
| 2000.00 | 4.0000 | 3.1965 | .94608 | 336.49 | .34932 | .0490 |
| 2000.00 | 3.0000 | 4.3213 | .95929 | 338.37 | .35419 | .0461 |
| 2000.00 | 2.0000 | 6.5723 | .97263 | 340.27 | .36082 | .0432 |
| 2000.00 | 1.0000 | 13.3262 | .98621 | 342.17 | .37174 | .0403 |
| 2000.00 | .8000 | 16.7065 | .98899 | 342.56 | .37519 | .0397 |
| 2000.00 | .6000 | 22.3373 | .99170 | 342.94 | .37960 | .0391 |
| 2000.00 | .4000 | 33.5991 | .99446 | 343.32 | .38578 | .0386 |
| 2000.00 | .2000 | 67.3851 | .99723 | 343.70 | .39625 | .0380 |
| 2025.00 | 16.9852 | .6404 | .79673 | 315.61 | .32172 | .0757 |
| 2025.00 | 16.0000 | .6893 | .80785 | 317.16 | .32306 | .0746 |
| 2025.00 | 15.0000 | .7455 | .81911 | 318.76 | .32449 | .0732 |
| 2025.00 | 14.0000 | .8097 | .83037 | 320.38 | .32599 | .0716 |
| 2025.00 | 13.0000 | .8839 | .84165 | 322.02 | .32758 | .0699 |
| 2025.00 | 12.0000 | .9704 | .85299 | 323.69 | .32926 | .0679 |
| 2025.00 | 11.0000 | 1.0728 | .86440 | 325.38 | .33106 | .0659 |
| 2025.00 | 10.0000 | 1.1958 | .87591 | 327.09 | .33299 | .0636 |
| 2025.00 | 9.0000 | 1.3463 | .88759 | 328.82 | .33507 | .0613 |
| 2025.00 | 8.0000 | 1.5347 | .89932 | 330.56 | .33735 | .0589 |
| 2025.00 | 7.0000 | 1.7772 | .91129 | 332.32 | .33986 | .0563 |
| 2025.00 | 6.0000 | 2.1009 | .92339 | 334.10 | .34269 | .0537 |
| 2025.00 | 5.0000 | 2.5546 | .93563 | 335.90 | .34595 | .0511 |
| 2025.00 | 4.0000 | 3.2358 | .94810 | 337.70 | .34982 | .0484 |
| 2025.00 | 3.0000 | 4.3721 | .96077 | 339.52 | .35465 | .0457 |
| 2025.00 | 2.0000 | 6.6461 | .97365 | 341.35 | .36125 | .0429 |
| 2025.00 | 1.0000 | 13.4706 | .98672 | 343.18 | .37215 | .0402 |
| 2025.00 | .8000 | 16.8833 | .98936 | 343.55 | .37559 | .0396 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| t | p | c_p | α | λ^2 | s^2 | c_p^2 |
|---------|---------|---------|----------|-------------|--------|---------|
| 2025.00 | .6000 | 22.5713 | .99231 | 343.91 | .38000 | .0391 |
| 2025.00 | .4000 | 33.9476 | .99466 | 344.28 | .38617 | .0385 |
| 2025.00 | .2000 | 68.0770 | .99733 | 344.65 | .39664 | .0380 |
| 2050.00 | 18.0294 | .6059 | .79227 | 315.90 | .32113 | .0756 |
| 2050.00 | 18.0000 | .6072 | .79260 | 315.94 | .32117 | .0756 |
| 2050.00 | 17.0000 | .6518 | .80362 | 317.47 | .32245 | .0745 |
| 2050.00 | 16.0000 | .7020 | .81458 | 319.01 | .32380 | .0733 |
| 2050.00 | 15.0000 | .7589 | .82551 | 320.57 | .32522 | .0718 |
| 2050.00 | 14.0000 | .8238 | .83642 | 322.15 | .32670 | .0702 |
| 2050.00 | 13.0000 | .8988 | .84734 | 323.75 | .32827 | .0684 |
| 2050.00 | 12.0000 | .9863 | .85831 | 325.37 | .32994 | .0665 |
| 2050.00 | 11.0000 | 1.0898 | .86934 | 327.01 | .33171 | .0645 |
| 2050.00 | 10.0000 | 1.2141 | .88049 | 328.68 | .33362 | .0623 |
| 2050.00 | 9.0000 | 1.3662 | .89167 | 330.33 | .33568 | .0601 |
| 2050.00 | 8.0000 | 1.5565 | .90302 | 332.02 | .33793 | .0577 |
| 2050.00 | 7.0000 | 1.8015 | .91452 | 333.72 | .34042 | .0553 |
| 2050.00 | 6.0000 | 2.1285 | .92617 | 335.44 | .34323 | .0529 |
| 2050.00 | 5.0000 | 2.5869 | .93800 | 337.16 | .34646 | .0503 |
| 2050.00 | 4.0000 | 3.2750 | .95001 | 338.91 | .35030 | .0478 |
| 2050.00 | 3.0000 | 4.4227 | .96221 | 340.66 | .35511 | .0452 |
| 2050.00 | 2.0000 | 6.7196 | .97461 | 342.42 | .36168 | .0426 |
| 2050.00 | 1.0000 | 13.6122 | .98721 | 344.18 | .37255 | .0400 |
| 2050.00 | .8000 | 17.0599 | .98975 | 344.54 | .37599 | .0395 |
| 2050.00 | .6000 | 22.8051 | .99230 | 344.89 | .38039 | .0390 |
| 2050.00 | .4000 | 34.2958 | .99486 | 345.24 | .38655 | .0384 |
| 2050.00 | .2000 | 68.7687 | .99743 | 345.60 | .39701 | .0379 |
| 2075.00 | 19.1142 | .5739 | .78767 | 316.17 | .32055 | .0756 |
| 2075.00 | 19.0000 | .5783 | .78891 | 316.34 | .32088 | .0755 |
| 2075.00 | 18.0000 | .6187 | .79970 | 317.82 | .32191 | .0745 |
| 2075.00 | 17.0000 | .6639 | .81041 | 319.31 | .32319 | .0733 |
| 2075.00 | 16.0000 | .7146 | .82105 | 320.82 | .32452 | .0719 |
| 2075.00 | 15.0000 | .7721 | .83163 | 322.35 | .32592 | .0704 |
| 2075.00 | 14.0000 | .8378 | .84220 | 323.89 | .32739 | .0688 |
| 2075.00 | 13.0000 | .9136 | .85277 | 325.45 | .32894 | .0670 |
| 2075.00 | 12.0000 | 1.0020 | .86337 | 327.02 | .33059 | .0652 |
| 2075.00 | 11.0000 | 1.1066 | .87402 | 328.60 | .33235 | .0631 |
| 2075.00 | 10.0000 | 1.2322 | .88475 | 330.20 | .33423 | .0611 |
| 2075.00 | 9.0000 | 1.3858 | .89558 | 331.82 | .33627 | .0589 |
| 2075.00 | 8.0000 | 1.5781 | .90652 | 333.45 | .33850 | .0567 |
| 2075.00 | 7.0000 | 1.8256 | .91761 | 335.09 | .34097 | .0544 |
| 2075.00 | 6.0000 | 2.1559 | .92884 | 336.75 | .34375 | .0520 |
| 2075.00 | 5.0000 | 2.6189 | .94024 | 338.41 | .34695 | .0496 |
| 2075.00 | 4.0000 | 3.3139 | .95181 | 340.09 | .35077 | .0472 |
| 2075.00 | 3.0000 | 4.4731 | .96357 | 341.78 | .35555 | .0448 |
| 2075.00 | 2.0000 | 6.7928 | .97532 | 343.48 | .36210 | .0423 |
| 2075.00 | 1.0000 | 13.7548 | .98766 | 345.18 | .37295 | .0399 |
| 2075.00 | .8000 | 17.2362 | .99011 | 345.52 | .37638 | .0394 |
| 2075.00 | .6000 | 23.0386 | .99257 | 345.86 | .38078 | .0389 |
| 2075.00 | .4000 | 34.6439 | .99504 | 346.20 | .38693 | .0384 |
| 2075.00 | .2000 | 69.4601 | .99752 | 346.55 | .39739 | .0379 |
| 2100.00 | 20.2402 | .5440 | .78290 | 316.43 | .31998 | .0756 |
| 2100.00 | 20.0000 | .5523 | .78546 | 316.77 | .32025 | .0754 |
| 2100.00 | 19.0000 | .5893 | .79606 | 318.21 | .32142 | .0744 |
| 2100.00 | 18.0000 | .6302 | .80654 | 319.47 | .32263 | .0733 |
| 2100.00 | 17.0000 | .6758 | .81693 | 321.13 | .32390 | .0720 |
| 2100.00 | 16.0000 | .7271 | .82723 | 322.61 | .32522 | .0706 |
| 2100.00 | 15.0000 | .7852 | .83749 | 324.09 | .32661 | .0691 |
| 2100.00 | 14.0000 | .8516 | .84771 | 325.59 | .32806 | .0674 |
| 2100.00 | 13.0000 | .9281 | .85793 | 327.10 | .32960 | .0657 |
| 2100.00 | 12.0000 | 1.0175 | .86818 | 328.63 | .33122 | .0638 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| t | p | v | u | h | h^* | c_p |
|---------|---------|---------|--------|--------|--------|-------|
| 2100.00 | 11.0000 | 1.1232 | .87847 | 330.17 | .33296 | .0619 |
| 2100.00 | 10.0000 | 1.2500 | .88883 | 331.72 | .33482 | .0599 |
| 2100.00 | 9.0000 | 1.4053 | .89928 | 333.28 | .33684 | .0576 |
| 2100.00 | 8.0000 | 1.5995 | .90984 | 334.85 | .33905 | .0557 |
| 2100.00 | 7.0000 | 1.8495 | .92053 | 336.44 | .34150 | .0535 |
| 2100.00 | 6.0000 | 2.1831 | .93137 | 338.04 | .34425 | .0513 |
| 2100.00 | 5.0000 | 2.6507 | .94236 | 339.65 | .34744 | .0490 |
| 2100.00 | 4.0000 | 3.3526 | .95352 | 341.27 | .35123 | .0467 |
| 2100.00 | 3.0000 | 4.5232 | .96486 | 342.90 | .35599 | .0444 |
| 2100.00 | 2.0000 | 6.8659 | .97638 | 344.53 | .36251 | .0421 |
| 2100.00 | 1.0000 | 13.8965 | .98810 | 346.18 | .37334 | .0397 |
| 2100.00 | .8000 | 17.4122 | .99046 | 346.50 | .37677 | .0393 |
| 2100.00 | .6000 | 23.2720 | .99283 | 346.83 | .38116 | .0388 |
| 2100.00 | .4000 | 34.9916 | .99521 | 347.16 | .38731 | .0383 |
| 2100.00 | .2000 | 70.1513 | .99760 | 347.49 | .39776 | .0379 |
| 2125.00 | 21.4077 | .5161 | .77297 | 316.66 | .31941 | .0757 |
| 2125.00 | 21.0000 | .5290 | .78225 | 317.23 | .31986 | .0753 |
| 2125.00 | 20.0000 | .5628 | .79267 | 318.64 | .32098 | .0744 |
| 2125.00 | 19.0000 | .6002 | .80295 | 320.06 | .32214 | .0733 |
| 2125.00 | 18.0000 | .6415 | .81311 | 321.48 | .32334 | .0720 |
| 2125.00 | 17.0000 | .6877 | .82317 | 322.91 | .32459 | .0707 |
| 2125.00 | 16.0000 | .7393 | .83315 | 324.35 | .32590 | .0693 |
| 2125.00 | 15.0000 | .7982 | .84307 | 325.80 | .32727 | .0677 |
| 2125.00 | 14.0000 | .8652 | .85296 | 327.26 | .32871 | .0661 |
| 2125.00 | 13.0000 | .9426 | .86285 | 328.73 | .33023 | .0643 |
| 2125.00 | 12.0000 | 1.0328 | .87275 | 330.21 | .33184 | .0626 |
| 2125.00 | 11.0000 | 1.1396 | .88269 | 331.70 | .33355 | .0607 |
| 2125.00 | 10.0000 | 1.2677 | .89270 | 333.20 | .33540 | .0588 |
| 2125.00 | 9.0000 | 1.4245 | .90279 | 334.71 | .33740 | .0568 |
| 2125.00 | 8.0000 | 1.6207 | .91299 | 336.23 | .33959 | .0547 |
| 2125.00 | 7.0000 | 1.8732 | .92330 | 337.77 | .34201 | .0527 |
| 2125.00 | 6.0000 | 2.2101 | .93376 | 339.31 | .34475 | .0505 |
| 2125.00 | 5.0000 | 2.6822 | .94436 | 340.86 | .34791 | .0484 |
| 2125.00 | 4.0000 | 3.3910 | .95513 | 342.43 | .35168 | .0462 |
| 2125.00 | 3.0000 | 4.5732 | .96608 | 344.00 | .35642 | .0440 |
| 2125.00 | 2.0000 | 6.9387 | .97720 | 345.58 | .36292 | .0418 |
| 2125.00 | 1.0000 | 14.0381 | .98850 | 347.17 | .37372 | .0396 |
| 2125.00 | .8000 | 17.5881 | .99079 | 347.49 | .37715 | .0392 |
| 2125.00 | .6000 | 23.5051 | .99308 | 347.80 | .38153 | .0387 |
| 2125.00 | .4000 | 35.3392 | .99538 | 348.12 | .38768 | .0383 |
| 2125.00 | .2000 | 70.8422 | .99769 | 348.44 | .39813 | .0379 |
| 2150.00 | 22.6171 | .4900 | .77288 | 316.87 | .31886 | .0758 |
| 2150.00 | 22.0000 | .5079 | .77927 | 317.72 | .31950 | .0753 |
| 2150.00 | 21.0000 | .5391 | .78952 | 319.10 | .32058 | .0743 |
| 2150.00 | 20.0000 | .5733 | .79961 | 320.49 | .32169 | .0732 |
| 2150.00 | 19.0000 | .6110 | .80957 | 321.88 | .32284 | .0721 |
| 2150.00 | 18.0000 | .6527 | .81941 | 323.27 | .32403 | .0708 |
| 2150.00 | 17.0000 | .6993 | .82915 | 324.67 | .32527 | .0694 |
| 2150.00 | 16.0000 | .7517 | .83881 | 326.07 | .32656 | .0679 |
| 2150.00 | 15.0000 | .8110 | .84841 | 327.48 | .32792 | .0664 |
| 2150.00 | 14.0000 | .8787 | .85797 | 328.90 | .32934 | .0648 |
| 2150.00 | 13.0000 | .9569 | .86753 | 330.32 | .33084 | .0631 |
| 2150.00 | 12.0000 | 1.0480 | .87710 | 331.76 | .33243 | .0614 |
| 2150.00 | 11.0000 | 1.1558 | .88671 | 333.20 | .33413 | .0596 |
| 2150.00 | 10.0000 | 1.2853 | .89637 | 334.65 | .33596 | .0577 |
| 2150.00 | 9.0000 | 1.4436 | .90612 | 336.12 | .33794 | .0558 |
| 2150.00 | 8.0000 | 1.6417 | .91597 | 337.59 | .34011 | .0539 |
| 2150.00 | 7.0000 | 1.8967 | .92593 | 339.07 | .34251 | .0519 |
| 2150.00 | 6.0000 | 2.2369 | .93603 | 340.57 | .34523 | .0499 |
| 2150.00 | 5.0000 | 2.7136 | .94627 | 342.07 | .34837 | .0478 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| T | P | v | u | h | s | f |
|---------|---------|---------|--------|--------|--------|-------|
| 2150.00 | 4.0000 | 3.4293 | .95666 | 343.58 | .35212 | .0458 |
| 2150.00 | 3.0000 | 4.6229 | .96723 | 345.10 | .35684 | .0437 |
| 2150.00 | 2.0000 | 7.0114 | .97797 | 346.62 | .36332 | .0416 |
| 2150.00 | 1.0000 | 14.1794 | .98889 | 348.16 | .37410 | .0395 |
| 2150.00 | .8000 | 17.7638 | .99110 | 348.46 | .37752 | .0391 |
| 2150.00 | .6000 | 23.7380 | .99331 | 348.77 | .38191 | .0387 |
| 2150.00 | .4000 | 35.6866 | .99553 | 349.08 | .38805 | .0383 |
| 2150.00 | .2000 | 71.5330 | .99776 | 349.39 | .39850 | .0378 |
| 2175.00 | 23.8687 | .4656 | .76765 | 317.06 | .31831 | .0759 |
| 2175.00 | 23.0000 | .4887 | .77652 | 318.24 | .31918 | .0752 |
| 2175.00 | 22.0000 | .5176 | .78559 | 319.59 | .32022 | .0743 |
| 2175.00 | 21.0000 | .5491 | .79651 | 320.95 | .32128 | .0732 |
| 2175.00 | 20.0000 | .5836 | .80629 | 322.30 | .32238 | .0721 |
| 2175.00 | 19.0000 | .6217 | .81593 | 323.66 | .32352 | .0708 |
| 2175.00 | 18.0000 | .6638 | .82545 | 325.02 | .32473 | .0695 |
| 2175.00 | 17.0000 | .7109 | .83487 | 326.38 | .32592 | .0681 |
| 2175.00 | 16.0000 | .7638 | .84421 | 327.75 | .32720 | .0666 |
| 2175.00 | 15.0000 | .8237 | .85349 | 329.12 | .32854 | .0651 |
| 2175.00 | 14.0000 | .8921 | .86274 | 330.50 | .32995 | .0635 |
| 2175.00 | 13.0000 | .9710 | .87198 | 331.88 | .33144 | .0619 |
| 2175.00 | 12.0000 | 1.0631 | .88124 | 333.28 | .33301 | .0602 |
| 2175.00 | 11.0000 | 1.1719 | .89052 | 334.68 | .33470 | .0585 |
| 2175.00 | 10.0000 | 1.3026 | .89987 | 336.08 | .33651 | .0567 |
| 2175.00 | 9.0000 | 1.4625 | .90928 | 337.50 | .33847 | .0549 |
| 2175.00 | 8.0000 | 1.6626 | .91880 | 338.93 | .34062 | .0530 |
| 2175.00 | 7.0000 | 1.9200 | .92842 | 340.36 | .34301 | .0512 |
| 2175.00 | 6.0000 | 2.2635 | .93817 | 341.80 | .34570 | .0492 |
| 2175.00 | 5.0000 | 2.7449 | .94807 | 343.25 | .34883 | .0473 |
| 2175.00 | 4.0000 | 3.4674 | .95811 | 344.72 | .35256 | .0453 |
| 2175.00 | 3.0000 | 4.6725 | .96832 | 346.19 | .35726 | .0434 |
| 2175.00 | 2.0000 | 7.0639 | .97870 | 347.66 | .36372 | .0414 |
| 2175.00 | 1.0000 | 14.3206 | .98926 | 349.14 | .37446 | .0394 |
| 2175.00 | .8000 | 17.9393 | .99139 | 349.44 | .37790 | .0390 |
| 2175.00 | .6000 | 23.9707 | .99353 | 349.74 | .38228 | .0386 |
| 2175.00 | .4000 | 36.0338 | .99568 | 350.04 | .38842 | .0382 |
| 2175.00 | .2000 | 72.2236 | .99784 | 350.33 | .39886 | .0376 |
| 2200.00 | 25.1638 | .4427 | .76233 | 317.23 | .31777 | .0761 |
| 2200.00 | 25.0000 | .4466 | .76397 | 317.44 | .31792 | .0760 |
| 2200.00 | 24.0000 | .4713 | .77399 | 318.78 | .31889 | .0752 |
| 2200.00 | 23.0000 | .4981 | .78389 | 320.11 | .31989 | .0742 |
| 2200.00 | 22.0000 | .5272 | .79364 | 321.44 | .32091 | .0732 |
| 2200.00 | 21.0000 | .5590 | .80324 | 322.76 | .32197 | .0721 |
| 2200.00 | 20.0000 | .5938 | .81269 | 324.09 | .32306 | .0708 |
| 2200.00 | 19.0000 | .6322 | .82202 | 325.42 | .32418 | .0696 |
| 2200.00 | 18.0000 | .6748 | .83123 | 326.74 | .32535 | .0682 |
| 2200.00 | 17.0000 | .7224 | .84034 | 328.07 | .32656 | .0668 |
| 2200.00 | 16.0000 | .7758 | .84937 | 329.40 | .32783 | .0654 |
| 2200.00 | 15.0000 | .8362 | .85835 | 330.74 | .32915 | .0639 |
| 2200.00 | 14.0000 | .9053 | .86729 | 332.07 | .33054 | .0624 |
| 2200.00 | 13.0000 | .9850 | .87623 | 333.42 | .33202 | .0608 |
| 2200.00 | 12.0000 | 1.0779 | .88517 | 334.77 | .33358 | .0592 |
| 2200.00 | 11.0000 | 1.1879 | .89415 | 336.13 | .33524 | .0575 |
| 2200.00 | 10.0000 | 1.3199 | .90318 | 337.49 | .33704 | .0558 |
| 2200.00 | 9.0000 | 1.4813 | .91229 | 338.86 | .33898 | .0540 |
| 2200.00 | 8.0000 | 1.6837 | .92149 | 340.24 | .34112 | .0523 |
| 2200.00 | 7.0000 | 1.9431 | .93079 | 341.63 | .34349 | .0505 |
| 2200.00 | 6.0000 | 2.2900 | .94021 | 343.03 | .34617 | .0487 |
| 2200.00 | 5.0000 | 2.7759 | .94978 | 344.43 | .34927 | .0468 |
| 2200.00 | 4.0000 | 3.5053 | .95949 | 345.85 | .35298 | .0450 |
| 2200.00 | 3.0000 | 4.7219 | .96936 | 347.27 | .35767 | .0431 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| T | P | C _p | h | h ^o | s ^o | C _p ^o |
|---------|---------|----------------|--------|----------------|----------------|-----------------------------|
| 2200.00 | 2.0000 | 7.1502 | .97940 | 348.69 | .36411 | .0412 |
| 2200.00 | 1.0000 | 14.4615 | .98961 | 350.13 | .37485 | .0393 |
| 2200.00 | .8000 | 18.1146 | .99167 | 350.42 | .37826 | .0389 |
| 2200.00 | .6070 | 24.2033 | .99374 | 350.70 | .38264 | .0386 |
| 2200.00 | .4000 | 36.3808 | .99582 | 350.99 | .38878 | .0382 |
| 2200.00 | .2000 | 72.9140 | .99791 | 351.28 | .39921 | .0378 |
| 2225.00 | 26.5001 | .4213 | .75696 | 317.37 | .31723 | .0763 |
| 2225.00 | 26.0000 | .4323 | .76189 | 318.02 | .31769 | .0760 |
| 2225.00 | 25.0000 | .4553 | .77170 | 319.33 | .31863 | .0752 |
| 2225.00 | 24.0000 | .4803 | .78141 | 320.64 | .31959 | .0742 |
| 2225.00 | 23.0000 | .5073 | .79090 | 321.95 | .32058 | .0732 |
| 2225.00 | 22.6000 | .5367 | .80041 | 323.25 | .32159 | .0720 |
| 2225.00 | 21.0000 | .5687 | .80969 | 324.55 | .32264 | .0709 |
| 2225.00 | 20.0000 | .6039 | .81884 | 325.85 | .32371 | .0696 |
| 2225.00 | 19.0000 | .6427 | .82795 | 327.14 | .32483 | .0683 |
| 2225.00 | 18.0000 | .6857 | .83675 | 328.43 | .32598 | .0670 |
| 2225.00 | 17.0000 | .7337 | .84556 | 329.73 | .32718 | .0656 |
| 2225.00 | 16.0000 | .7876 | .85429 | 331.02 | .32843 | .0642 |
| 2225.00 | 15.0000 | .8486 | .86298 | 332.32 | .32974 | .0627 |
| 2225.00 | 14.0000 | .9184 | .87163 | 333.62 | .33112 | .0612 |
| 2225.00 | 13.0000 | .9988 | .88027 | 334.92 | .33258 | .0597 |
| 2225.00 | 12.0000 | 1.0927 | .88892 | 336.23 | .33413 | .0581 |
| 2225.00 | 11.0000 | 1.2037 | .89760 | 337.55 | .33578 | .0565 |
| 2225.00 | 10.0000 | 1.3369 | .90634 | 338.87 | .33755 | .0549 |
| 2225.00 | 9.0000 | 1.4999 | .91515 | 340.20 | .33948 | .0532 |
| 2225.00 | 8.0000 | 1.7038 | .92404 | 341.54 | .34160 | .0516 |
| 2225.00 | 7.0000 | 1.9661 | .93304 | 342.88 | .34395 | .0498 |
| 2225.00 | 6.0000 | 2.3162 | .94215 | 344.24 | .34682 | .0481 |
| 2225.00 | 5.0000 | 2.8068 | .95140 | 345.60 | .34971 | .0464 |
| 2225.00 | 4.0000 | 3.5431 | .96079 | 346.96 | .35340 | .0446 |
| 2225.00 | 3.0000 | 4.7711 | .97034 | 348.34 | .35807 | .0428 |
| 2225.00 | 2.0000 | 7.2283 | .98006 | 349.72 | .36449 | .0410 |
| 2225.00 | 1.0000 | 14.6024 | .98994 | 351.11 | .37522 | .0392 |
| 2225.00 | .8000 | 18.2898 | .99194 | 351.39 | .37863 | .0389 |
| 2225.00 | .6000 | 24.4357 | .99394 | 351.67 | .38300 | .0385 |
| 2225.00 | .4000 | 36.7277 | .99595 | 351.95 | .38913 | .0382 |
| 2225.00 | .2000 | 73.6043 | .99797 | 352.22 | .39957 | .0378 |
| 2250.00 | 27.8803 | .4014 | .75165 | 317.49 | .31670 | .0766 |
| 2250.00 | 27.0000 | .4191 | .76009 | 318.62 | .31749 | .0760 |
| 2250.00 | 26.0000 | .4407 | .76967 | 319.91 | .31839 | .0751 |
| 2250.00 | 25.0000 | .4640 | .77917 | 321.20 | .31932 | .0742 |
| 2250.00 | 24.0000 | .4892 | .78856 | 322.49 | .32028 | .0731 |
| 2250.00 | 23.0000 | .5164 | .79781 | 323.76 | .32125 | .0720 |
| 2250.00 | 22.0000 | .5451 | .80592 | 325.04 | .32225 | .0709 |
| 2250.00 | 21.0000 | .5784 | .81589 | 326.31 | .32329 | .0697 |
| 2250.00 | 20.0000 | .6139 | .82472 | 327.57 | .32435 | .0684 |
| 2250.00 | 19.0000 | .6531 | .83343 | 328.83 | .32545 | .0671 |
| 2250.00 | 18.0000 | .6965 | .84203 | 330.09 | .32660 | .0658 |
| 2250.00 | 17.0000 | .7449 | .85055 | 331.35 | .32778 | .0644 |
| 2250.00 | 16.0000 | .7993 | .85900 | 332.61 | .32902 | .0630 |
| 2250.00 | 15.0000 | .8609 | .86739 | 333.87 | .33032 | .0616 |
| 2250.00 | 14.0000 | .9313 | .87576 | 335.14 | .33169 | .0602 |
| 2250.00 | 13.0000 | 1.0125 | .88412 | 336.40 | .33313 | .0587 |
| 2250.00 | 12.0000 | 1.1073 | .89249 | 337.68 | .33466 | .0572 |
| 2250.00 | 11.0000 | 1.2193 | .90089 | 338.95 | .33630 | .0556 |
| 2250.00 | 10.0000 | 1.3538 | .90934 | 340.24 | .33806 | .0541 |
| 2250.00 | 9.0000 | 1.5184 | .91786 | 341.52 | .33997 | .0525 |
| 2250.00 | 8.0000 | 1.7242 | .92647 | 342.82 | .34208 | .0509 |
| 2250.00 | 7.0000 | 1.9890 | .93517 | 344.12 | .34441 | .0492 |
| 2250.00 | 6.0000 | 2.3424 | .94399 | 345.43 | .34706 | .0476 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| T | P | c_p | z | A^2 | v^2 | c_p^2 |
|---------|---------|---------|--------|--------|--------|---------|
| 2250.00 | 5.0000 | 2.8375 | .95294 | 346.75 | .35013 | .0459 |
| 2250.00 | 4.0000 | 3.5807 | .96204 | 348.07 | .35382 | .0442 |
| 2250.00 | 3.0000 | 4.8202 | .97128 | 349.41 | .35846 | .0426 |
| 2250.00 | 2.0000 | 7.3003 | .98068 | 350.75 | .36487 | .0409 |
| 2250.00 | 1.0000 | 14.7430 | .99025 | 352.09 | .37558 | .0392 |
| 2250.00 | .8000 | 18.4648 | .99219 | 352.36 | .37899 | .0388 |
| 2250.00 | .6000 | 24.6679 | .99413 | 352.63 | .38336 | .0385 |
| 2250.00 | .4000 | 37.0744 | .99608 | 352.90 | .38949 | .0381 |
| 2250.00 | .2000 | 74.2944 | .99804 | 353.17 | .39992 | .0378 |
| 2275.00 | 29.3039 | .3828 | .74650 | 317.59 | .31618 | .0168 |
| 2275.00 | 29.0000 | .3882 | .74930 | 317.97 | .31644 | .0167 |
| 2275.00 | 28.0000 | .4071 | .75858 | 319.24 | .31730 | .0176 |
| 2275.00 | 27.0000 | .4273 | .76790 | 320.51 | .31818 | .0175 |
| 2275.00 | 26.0000 | .4491 | .77717 | 321.78 | .31908 | .0174 |
| 2275.00 | 25.0000 | .4726 | .78636 | 323.04 | .32000 | .0173 |
| 2275.00 | 24.0000 | .4983 | .79543 | 324.30 | .32094 | .0172 |
| 2275.00 | 23.0000 | .5255 | .80436 | 325.55 | .32191 | .0170 |
| 2275.00 | 22.0000 | .5554 | .81316 | 326.79 | .32290 | .0169 |
| 2275.00 | 21.0000 | .5860 | .82182 | 328.03 | .32392 | .0168 |
| 2275.00 | 20.0000 | .6238 | .83035 | 329.27 | .32497 | .0167 |
| 2275.00 | 19.0000 | .6633 | .83877 | 330.50 | .32606 | .0165 |
| 2275.00 | 18.0000 | .7071 | .84708 | 331.72 | .32719 | .0164 |
| 2275.00 | 17.0000 | .7560 | .85532 | 332.95 | .32837 | .0163 |
| 2275.00 | 16.0000 | .8109 | .86349 | 334.17 | .32960 | .0161 |
| 2275.00 | 15.0000 | .8731 | .87161 | 335.40 | .33088 | .0160 |
| 2275.00 | 14.0000 | .9441 | .87970 | 336.63 | .33223 | .0159 |
| 2275.00 | 13.0000 | 1.0261 | .88779 | 337.86 | .33366 | .0157 |
| 2275.00 | 12.0000 | 1.1218 | .89589 | 339.09 | .33518 | .0156 |
| 2275.00 | 11.0000 | 1.2348 | .90402 | 340.33 | .33680 | .0154 |
| 2275.00 | 10.0000 | 1.3706 | .91220 | 341.58 | .33855 | .0153 |
| 2275.00 | 9.0000 | 1.5367 | .92045 | 342.83 | .34045 | .0151 |
| 2275.00 | 8.0000 | 1.7444 | .92878 | 344.08 | .34254 | .0150 |
| 2275.00 | 7.0000 | 2.0117 | .93721 | 345.35 | .34486 | .0149 |
| 2275.00 | 6.0000 | 2.3684 | .94575 | 346.62 | .34750 | .0147 |
| 2275.00 | 5.0000 | 2.8681 | .95441 | 347.89 | .35055 | .0145 |
| 2275.00 | 4.0000 | 3.6182 | .96322 | 349.18 | .35422 | .0143 |
| 2275.00 | 3.0000 | 4.8691 | .97217 | 350.47 | .35885 | .0142 |
| 2275.00 | 2.0000 | 7.3721 | .98128 | 351.76 | .36525 | .0140 |
| 2275.00 | 1.0000 | 14.8835 | .99055 | 353.07 | .37594 | .0139 |
| 2275.00 | .8000 | 18.6397 | .99243 | 353.33 | .37934 | .0138 |
| 2275.00 | .6000 | 24.9000 | .99431 | 353.59 | .38371 | .0138 |
| 2275.00 | .4000 | 37.4210 | .99620 | 353.85 | .38984 | .0138 |
| 2275.00 | .2000 | 74.9844 | .99810 | 354.11 | .40026 | .0137 |
| 2300.00 | 30.7711 | .3655 | .74169 | 317.68 | .31567 | .0170 |
| 2300.00 | 30.0000 | .3783 | .74846 | 318.64 | .31630 | .0166 |
| 2300.00 | 29.0000 | .3960 | .75739 | 319.86 | .31714 | .0159 |
| 2300.00 | 28.0000 | .4150 | .76640 | 321.13 | .31799 | .0151 |
| 2300.00 | 27.0000 | .4355 | .77542 | 322.38 | .31886 | .0142 |
| 2300.00 | 26.0000 | .4574 | .78439 | 323.62 | .31975 | .0131 |
| 2300.00 | 25.0000 | .4811 | .79326 | 324.86 | .32066 | .0120 |
| 2300.00 | 24.0000 | .5067 | .80202 | 326.09 | .32159 | .0109 |
| 2300.00 | 23.0000 | .5344 | .81064 | 327.31 | .32255 | .0097 |
| 2300.00 | 22.0000 | .5646 | .81914 | 328.52 | .32353 | .0085 |
| 2300.00 | 21.0000 | .5975 | .82750 | 329.73 | .32454 | .0073 |
| 2300.00 | 20.0000 | .6336 | .83574 | 330.93 | .32558 | .0060 |
| 2300.00 | 19.0000 | .6734 | .84387 | 332.13 | .32666 | .0048 |
| 2300.00 | 18.0000 | .7176 | .85191 | 333.33 | .32778 | .0035 |
| 2300.00 | 17.0000 | .7669 | .85987 | 334.52 | .32894 | .0022 |
| 2300.00 | 16.0000 | .8224 | .86777 | 335.71 | .33016 | .0009 |
| 2300.00 | 15.0000 | .8851 | .87563 | 336.90 | .33143 | .0006 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| t | p | c_p | z | h^0 | s^0 | c_p^0 |
|---------|---------|---------|--------|--------|--------|---------|
| 2300.00 | 14.0000 | .9560 | .88346 | 338.10 | .33277 | .0582 |
| 2300.00 | 13.0000 | 1.0396 | .89129 | 339.29 | .33418 | .0568 |
| 2300.00 | 12.0000 | 1.1361 | .89913 | 340.49 | .33569 | .0554 |
| 2300.00 | 11.0000 | 1.2503 | .90700 | 341.69 | .33730 | .0540 |
| 2300.00 | 10.0000 | 1.3873 | .91493 | 342.90 | .33903 | .0525 |
| 2300.00 | 9.0000 | 1.5549 | .92291 | 344.11 | .34092 | .0511 |
| 2300.00 | 8.0000 | 1.7645 | .93098 | 345.33 | .34299 | .0496 |
| 2300.00 | 7.0000 | 2.0343 | .93914 | 346.56 | .34530 | .0482 |
| 2300.00 | 6.0000 | 2.3942 | .94741 | 347.79 | .34792 | .0467 |
| 2300.00 | 5.0000 | 2.8986 | .95581 | 349.03 | .35097 | .0451 |
| 2300.00 | 4.0000 | 3.6555 | .96434 | 350.27 | .35462 | .0436 |
| 2300.00 | 3.0000 | 4.9179 | .97302 | 351.52 | .35924 | .0421 |
| 2300.00 | 2.0000 | 7.4438 | .98185 | 352.78 | .36562 | .0406 |
| 2300.00 | 1.0000 | 15.0239 | .99084 | 354.04 | .37630 | .0390 |
| 2300.00 | .8000 | 18.8144 | .99266 | 354.30 | .37970 | .0387 |
| 2300.00 | .6000 | 25.1320 | .99448 | 354.55 | .38425 | .0384 |
| 2300.00 | .4000 | 37.7674 | .99632 | 354.81 | .39019 | .0381 |
| 2300.00 | .2000 | 75.6742 | .99815 | 355.06 | .40061 | .0378 |
| 2325.00 | 32.2820 | .3495 | .73741 | 317.77 | .31518 | .0771 |
| 2325.00 | 32.0000 | .3537 | .73968 | 318.11 | .31540 | .0770 |
| 2325.00 | 31.0000 | .3692 | .74797 | 319.32 | .31618 | .0765 |
| 2325.00 | 30.0000 | .3858 | .75652 | 320.54 | .31694 | .0758 |
| 2325.00 | 29.0000 | .4037 | .76520 | 321.77 | .31782 | .0751 |
| 2325.00 | 28.0000 | .4229 | .77395 | 323.00 | .31864 | .0741 |
| 2325.00 | 27.0000 | .4435 | .78267 | 324.22 | .31952 | .0731 |
| 2325.00 | 26.0000 | .4657 | .79133 | 325.44 | .32040 | .0720 |
| 2325.00 | 25.0000 | .4895 | .79990 | 326.64 | .32130 | .0709 |
| 2325.00 | 24.0000 | .5153 | .80834 | 327.84 | .32223 | .0697 |
| 2325.00 | 23.0000 | .5433 | .81667 | 329.04 | .32317 | .0685 |
| 2325.00 | 22.0000 | .5737 | .82486 | 330.22 | .32414 | .0673 |
| 2325.00 | 21.0000 | .6069 | .83294 | 331.40 | .32514 | .0661 |
| 2325.00 | 20.0000 | .6433 | .84090 | 332.57 | .32617 | .0649 |
| 2325.00 | 19.0000 | .6835 | .84876 | 333.74 | .32724 | .0637 |
| 2325.00 | 18.0000 | .7281 | .85653 | 334.90 | .32835 | .0624 |
| 2325.00 | 17.0000 | .7778 | .86422 | 336.06 | .32950 | .0612 |
| 2325.00 | 16.0000 | .8337 | .87187 | 337.22 | .33070 | .0599 |
| 2325.00 | 15.0000 | .8971 | .87947 | 338.38 | .33196 | .0586 |
| 2325.00 | 14.0000 | .9694 | .88705 | 339.54 | .33329 | .0573 |
| 2325.00 | 13.0000 | 1.0529 | .89463 | 340.70 | .33469 | .0560 |
| 2325.00 | 12.0000 | 1.1503 | .90222 | 341.87 | .33619 | .0546 |
| 2325.00 | 11.0000 | 1.2655 | .90985 | 343.03 | .33778 | .0533 |
| 2325.00 | 10.0000 | 1.4038 | .91752 | 344.21 | .33951 | .0519 |
| 2325.00 | 9.0000 | 1.5730 | .92526 | 345.38 | .34138 | .0505 |
| 2325.00 | 8.0000 | 1.7845 | .93307 | 346.57 | .34344 | .0491 |
| 2325.00 | 7.0000 | 2.0567 | .94098 | 347.76 | .34574 | .0477 |
| 2325.00 | 6.0000 | 2.4200 | .94900 | 348.95 | .34834 | .0462 |
| 2325.00 | 5.0000 | 2.9289 | .95714 | 350.15 | .35137 | .0448 |
| 2325.00 | 4.0000 | 3.6927 | .96541 | 351.36 | .35501 | .0433 |
| 2325.00 | 3.0000 | 4.9666 | .97382 | 352.57 | .35962 | .0419 |
| 2325.00 | 2.0000 | 7.5154 | .98239 | 353.79 | .36598 | .0404 |
| 2325.00 | 1.0000 | 15.1642 | .99111 | 355.02 | .37665 | .0390 |
| 2325.00 | .8000 | 18.9899 | .99288 | 355.27 | .38005 | .0387 |
| 2325.00 | .6000 | 25.3638 | .99465 | 355.51 | .38441 | .0384 |
| 2325.00 | .4000 | 38.1137 | .99642 | 355.76 | .39053 | .0381 |
| 2325.00 | .2000 | 76.3639 | .99821 | 356.00 | .40095 | .0378 |
| 2350.00 | 33.8367 | .3348 | .73386 | 317.88 | .31470 | .0769 |
| 2350.00 | 33.0000 | .3462 | .74005 | 318.85 | .31532 | .0768 |
| 2350.00 | 32.0000 | .3608 | .74786 | 320.03 | .31608 | .0764 |
| 2350.00 | 31.0000 | .3765 | .75598 | 321.22 | .31686 | .0758 |
| 2350.00 | 30.0000 | .3933 | .76431 | 322.43 | .31767 | .0750 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| t | p | v | z | h^o | u | s |
|---------|---------|---------|--------|--------|--------|-------|
| 2350.00 | 29.0000 | .4114 | .77275 | 323.63 | .31848 | .0741 |
| 2350.00 | 28.0000 | .4307 | .78121 | 324.84 | .31932 | .0731 |
| 2350.00 | 27.0000 | .4515 | .78964 | 326.03 | .32017 | .0720 |
| 2350.00 | 26.0000 | .4738 | .79800 | 327.22 | .32104 | .0709 |
| 2350.00 | 25.0000 | .4979 | .80626 | 328.40 | .32193 | .0697 |
| 2350.00 | 24.0000 | .5239 | .81441 | 329.57 | .32284 | .0686 |
| 2350.00 | 23.0000 | .5520 | .82244 | 330.73 | .32376 | .0674 |
| 2350.00 | 22.0000 | .5827 | .83035 | 331.69 | .32474 | .0662 |
| 2350.00 | 21.0000 | .6161 | .83814 | 333.04 | .32573 | .0650 |
| 2350.00 | 20.0000 | .6529 | .84583 | 334.18 | .32675 | .0638 |
| 2350.00 | 19.0000 | .6934 | .85343 | 335.31 | .32780 | .0626 |
| 2350.00 | 18.0000 | .7384 | .86094 | 336.45 | .32890 | .0614 |
| 2350.00 | 17.0000 | .7886 | .86838 | 337.58 | .33004 | .0602 |
| 2350.00 | 16.0000 | .8450 | .87578 | 338.70 | .33123 | .0589 |
| 2350.00 | 15.0000 | .9089 | .88314 | 339.83 | .33248 | .0577 |
| 2350.00 | 14.0000 | .9819 | .89048 | 340.96 | .33380 | .0564 |
| 2350.00 | 13.0000 | 1.0662 | .89782 | 342.09 | .33519 | .0552 |
| 2350.00 | 12.0000 | 1.1645 | .90517 | 343.22 | .33667 | .0539 |
| 2350.00 | 11.0000 | 1.2807 | .91256 | 344.36 | .33826 | .0526 |
| 2350.00 | 10.0000 | 1.4202 | .92000 | 345.50 | .33997 | .0512 |
| 2350.00 | 9.0000 | 1.5909 | .92750 | 346.64 | .34183 | .0499 |
| 2350.00 | 8.0000 | 1.8044 | .93507 | 347.79 | .34386 | .0486 |
| 2350.00 | 7.0000 | 2.0791 | .94274 | 348.94 | .34616 | .0472 |
| 2350.00 | 6.0000 | 2.4456 | .95052 | 350.10 | .34875 | .0458 |
| 2350.00 | 5.0000 | 2.9591 | .95841 | 351.27 | .35177 | .0445 |
| 2350.00 | 4.0000 | 3.7298 | .96643 | 352.44 | .35540 | .0431 |
| 2350.00 | 3.0000 | 5.0151 | .97459 | 353.62 | .35999 | .0417 |
| 2350.00 | 2.0000 | 7.5868 | .98290 | 354.80 | .36634 | .0403 |
| 2350.00 | 1.0000 | 15.3043 | .99137 | 355.99 | .37700 | .0389 |
| 2350.00 | .8000 | 19.1635 | .99308 | 356.23 | .38039 | .0386 |
| 2350.00 | .6000 | 25.5955 | .99480 | 356.47 | .38475 | .0383 |
| 2350.00 | .4000 | 38.4599 | .99653 | 356.71 | .39087 | .0381 |
| 2350.00 | .2000 | 77.0535 | .99826 | 356.95 | .40129 | .0378 |
| 2375.00 | 34.0000 | .3394 | .74083 | 319.61 | .31526 | .0766 |
| 2375.00 | 33.0000 | .3531 | .74813 | 320.76 | .31600 | .0762 |
| 2375.00 | 32.0000 | .3679 | .75580 | 321.93 | .31676 | .0757 |
| 2375.00 | 31.0000 | .3837 | .76374 | 323.11 | .31753 | .0749 |
| 2375.00 | 30.0000 | .4007 | .77184 | 324.29 | .31833 | .0740 |
| 2375.00 | 29.0000 | .4189 | .78001 | 325.47 | .31914 | .0730 |
| 2375.00 | 28.0000 | .4384 | .78819 | 326.65 | .31996 | .0720 |
| 2375.00 | 27.0000 | .4594 | .79632 | 327.82 | .32080 | .0709 |
| 2375.00 | 26.0000 | .4819 | .80439 | 328.98 | .32167 | .0699 |
| 2375.00 | 25.0000 | .5061 | .81236 | 330.13 | .32255 | .0688 |
| 2375.00 | 24.0000 | .5323 | .82022 | 331.27 | .32345 | .0674 |
| 2375.00 | 23.0000 | .5607 | .82796 | 332.41 | .32437 | .0663 |
| 2375.00 | 22.0000 | .5916 | .83560 | 333.53 | .32532 | .0651 |
| 2375.00 | 21.0000 | .6253 | .84312 | 334.65 | .32630 | .0639 |
| 2375.00 | 20.0000 | .6624 | .85055 | 335.76 | .32731 | .0628 |
| 2375.00 | 19.0000 | .7032 | .85789 | 336.87 | .32835 | .0616 |
| 2375.00 | 18.0000 | .7486 | .86516 | 337.97 | .32944 | .0604 |
| 2375.00 | 17.0000 | .7992 | .87236 | 339.07 | .33057 | .0592 |
| 2375.00 | 16.0000 | .8561 | .87952 | 340.17 | .33175 | .0580 |
| 2375.00 | 15.0000 | .9206 | .88664 | 341.26 | .33299 | .0568 |
| 2375.00 | 14.0000 | .9943 | .89375 | 342.36 | .33429 | .0556 |
| 2375.00 | 13.0000 | 1.0793 | .90086 | 343.46 | .33567 | .0544 |
| 2375.00 | 12.0000 | 1.1785 | .90799 | 344.56 | .33714 | .0531 |
| 2375.00 | 11.0000 | 1.2958 | .91515 | 345.66 | .33871 | .0519 |
| 2375.00 | 10.0000 | 1.4366 | .92236 | 346.77 | .34042 | .0506 |
| 2375.00 | 9.0000 | 1.6088 | .92963 | 347.88 | .34227 | .0494 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| t | p | v^g | z | h^g | s^g | c_p^g |
|---------|---------|---------|--------|--------|--------|---------|
| 2375.00 | 6.0000 | 1.8242 | .93698 | 349.50 | .34430 | .0481 |
| 2375.00 | 7.0000 | 2.1013 | .94442 | 350.12 | .34658 | .0465 |
| 2375.00 | 8.0000 | 2.4711 | .95196 | 351.24 | .34916 | .0450 |
| 2375.00 | 9.0000 | 2.9892 | .95952 | 352.35 | .35216 | .0442 |
| 2375.00 | 1.0000 | 3.7668 | .96740 | 353.51 | .35576 | .0426 |
| 2375.00 | 3.0000 | 5.0635 | .97533 | 354.66 | .36036 | .0415 |
| 2375.00 | 2.0000 | 7.6581 | .98340 | 355.81 | .36670 | .0402 |
| 2375.00 | 1.0000 | 15.4443 | .99162 | 356.96 | .37734 | .0384 |
| 2375.00 | .8000 | 19.5378 | .99328 | 357.20 | .38073 | .0380 |
| 2375.00 | .6000 | 25.8271 | .99495 | 357.43 | .38509 | .0383 |
| 2375.00 | .4000 | 38.8059 | .99663 | 357.66 | .39121 | .0381 |
| 2375.00 | .2000 | 77.7430 | .99831 | 357.89 | .40162 | .0376 |
| 2400.00 | 34.0000 | .5460 | .74878 | 321.52 | .31593 | .0761 |
| 2400.00 | 33.0000 | .5559 | .75598 | 322.65 | .31666 | .0755 |
| 2400.00 | 32.0000 | .5749 | .76350 | 323.41 | .31742 | .0748 |
| 2400.00 | 31.0000 | .5969 | .77123 | 324.47 | .31819 | .0739 |
| 2400.00 | 30.0000 | .6060 | .77908 | 326.13 | .31897 | .0730 |
| 2400.00 | 29.0000 | .6264 | .78699 | 327.28 | .31977 | .0719 |
| 2400.00 | 28.0000 | .6461 | .79489 | 328.43 | .32059 | .0708 |
| 2400.00 | 27.0000 | .6671 | .80274 | 329.58 | .32142 | .0694 |
| 2400.00 | 26.0000 | .6898 | .81051 | 330.71 | .32227 | .0686 |
| 2400.00 | 25.0000 | .7142 | .81820 | 331.83 | .32314 | .0675 |
| 2400.00 | 24.0000 | .7406 | .82578 | 332.94 | .32403 | .0663 |
| 2400.00 | 23.0000 | .7692 | .83325 | 334.05 | .32495 | .0652 |
| 2400.00 | 22.0000 | .8004 | .84062 | 335.15 | .32589 | .0640 |
| 2400.00 | 21.0000 | .8344 | .84789 | 336.23 | .32685 | .0629 |
| 2400.00 | 20.0000 | .8718 | .85507 | 337.32 | .32785 | .0618 |
| 2400.00 | 19.0000 | .9130 | .86216 | 338.39 | .32889 | .0606 |
| 2400.00 | 18.0000 | .9587 | .86919 | 339.47 | .32996 | .0595 |
| 2400.00 | 17.0000 | .8098 | .87616 | 340.54 | .33108 | .0583 |
| 2400.00 | 16.0000 | .8672 | .88309 | 341.61 | .33225 | .0572 |
| 2400.00 | 15.0000 | .9323 | .88999 | 342.67 | .33348 | .0560 |
| 2400.00 | 14.0000 | 1.0066 | .89688 | 343.74 | .33478 | .0548 |
| 2400.00 | 13.0000 | 1.0923 | .90377 | 344.81 | .33615 | .0537 |
| 2400.00 | 12.0000 | 1.1924 | .91068 | 345.88 | .33761 | .0525 |
| 2400.00 | 11.0000 | 1.3107 | .91762 | 346.95 | .33917 | .0513 |
| 2400.00 | 10.0000 | 1.4528 | .92462 | 348.03 | .34086 | .0501 |
| 2400.00 | 9.0000 | 1.6265 | .93167 | 349.11 | .34270 | .0488 |
| 2400.00 | 8.0000 | 1.8438 | .93880 | 350.19 | .34472 | .0476 |
| 2400.00 | 7.0000 | 2.1234 | .94602 | 351.28 | .34699 | .0464 |
| 2400.00 | 6.0000 | 2.4965 | .95334 | 352.38 | .34956 | .0451 |
| 2400.00 | 5.0000 | 3.0192 | .96077 | 353.48 | .35255 | .0439 |
| 2400.00 | 4.0000 | 3.8037 | .96833 | 354.58 | .35615 | .0426 |
| 2400.00 | 3.0000 | 5.1119 | .97603 | 355.69 | .36072 | .0413 |
| 2400.00 | 2.0000 | 7.7294 | .98386 | 356.81 | .36705 | .0401 |
| 2400.00 | 1.0000 | 15.5843 | .99185 | 357.93 | .37768 | .0386 |
| 2400.00 | .8000 | 19.5121 | .99347 | 358.16 | .38107 | .0385 |
| 2400.00 | .6000 | 26.0586 | .99509 | 358.39 | .38543 | .0383 |
| 2400.00 | .4000 | 35.1519 | .99672 | 358.61 | .39154 | .0381 |
| 2400.00 | .2000 | 78.4323 | .99836 | 358.84 | .40195 | .0378 |
| 2425.00 | 34.0000 | .5527 | .75652 | 323.41 | .31659 | .0753 |
| 2425.00 | 33.0000 | .5667 | .76360 | 324.54 | .31732 | .0746 |
| 2425.00 | 32.0000 | .5818 | .77094 | 325.67 | .31806 | .0738 |
| 2425.00 | 31.0000 | .5980 | .77845 | 326.80 | .31882 | .0729 |
| 2425.00 | 30.0000 | .6153 | .78605 | 327.94 | .31960 | .0719 |
| 2425.00 | 29.0000 | .6336 | .79369 | 329.07 | .32039 | .0708 |
| 2425.00 | 28.0000 | .6536 | .80131 | 330.19 | .32120 | .0697 |
| 2425.00 | 27.0000 | .6748 | .80889 | 331.30 | .32202 | .0686 |
| 2425.00 | 26.0000 | .6977 | .81638 | 332.41 | .32287 | .0675 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| t | p | r^2 | z | h^2 | s^2 | c_p^2 |
|---------|---------|---------|--------|--------|--------|---------|
| 2425.00 | 25.0000 | .5223 | .82379 | 333.59 | .32373 | .0664 |
| 2425.00 | 24.0000 | .5469 | .83111 | 334.59 | .32461 | .0652 |
| 2425.00 | 23.0000 | .5777 | .83832 | 335.67 | .32551 | .0641 |
| 2425.00 | 22.0000 | .6091 | .84543 | 336.73 | .32644 | .0630 |
| 2425.00 | 21.0000 | .6434 | .85246 | 337.79 | .32740 | .0619 |
| 2425.00 | 20.0000 | .6811 | .85939 | 338.85 | .32839 | .0608 |
| 2425.00 | 19.0000 | .7226 | .86625 | 339.90 | .32941 | .0597 |
| 2425.00 | 18.0000 | .7688 | .87305 | 340.94 | .33048 | .0586 |
| 2425.00 | 17.0000 | .8203 | .87980 | 341.99 | .33159 | .0575 |
| 2425.00 | 16.0000 | .8782 | .88651 | 343.03 | .33275 | .0564 |
| 2425.00 | 15.0000 | .9438 | .89319 | 344.06 | .33397 | .0552 |
| 2425.00 | 14.0000 | 1.0188 | .89987 | 345.10 | .33525 | .0541 |
| 2425.00 | 13.0000 | 1.1053 | .90655 | 346.14 | .33661 | .0530 |
| 2425.00 | 12.0000 | 1.2062 | .91325 | 347.18 | .33806 | .0518 |
| 2425.00 | 11.0000 | 1.3256 | .91999 | 348.23 | .33962 | .0507 |
| 2425.00 | 10.0000 | 1.4669 | .92677 | 349.27 | .34129 | .0495 |
| 2425.00 | 9.0000 | 1.6442 | .93362 | 350.32 | .34312 | .0484 |
| 2425.00 | 8.0000 | 1.8634 | .94054 | 351.37 | .34514 | .0472 |
| 2425.00 | 7.0000 | 2.1455 | .94755 | 352.44 | .34739 | .0460 |
| 2425.00 | 6.0000 | 2.5218 | .95465 | 353.50 | .34995 | .0448 |
| 2425.00 | 5.0000 | 3.0491 | .96188 | 354.57 | .35293 | .0436 |
| 2425.00 | 4.0000 | 3.8404 | .96922 | 355.64 | .35652 | .0424 |
| 2425.00 | 3.0000 | 5.1601 | .97670 | 356.73 | .36108 | .0412 |
| 2425.00 | 2.0000 | 7.8005 | .98431 | 357.81 | .36740 | .0400 |
| 2425.00 | 1.0000 | 15.7241 | .99208 | 358.90 | .37802 | .0388 |
| 2425.00 | .8000 | 19.6862 | .99365 | 359.12 | .38141 | .0385 |
| 2425.00 | .6000 | 26.2950 | .99523 | 359.34 | .38576 | .0383 |
| 2425.00 | .4000 | 39.4978 | .99681 | 359.56 | .39187 | .0380 |
| 2425.00 | .2000 | 79.1216 | .99840 | 359.78 | .40228 | .0376 |
| 2450.00 | 34.0000 | .3593 | .76403 | 325.28 | .31724 | .0744 |
| 2450.00 | 33.0000 | .3735 | .77096 | 326.39 | .31796 | .0736 |
| 2450.00 | 32.0000 | .3887 | .77811 | 327.50 | .31870 | .0728 |
| 2450.00 | 31.0000 | .4050 | .78539 | 328.61 | .31945 | .0719 |
| 2450.00 | 30.0000 | .4225 | .79275 | 329.72 | .32022 | .0710 |
| 2450.00 | 29.0000 | .4411 | .80012 | 330.82 | .32100 | .0701 |
| 2450.00 | 28.0000 | .4610 | .80748 | 331.92 | .32180 | .0688 |
| 2450.00 | 27.0000 | .4824 | .81478 | 333.01 | .32261 | .0675 |
| 2450.00 | 26.0000 | .5054 | .82201 | 334.18 | .32344 | .0664 |
| 2450.00 | 25.0000 | .5302 | .82916 | 335.35 | .32429 | .0653 |
| 2450.00 | 24.0000 | .5570 | .83621 | 336.51 | .32516 | .0642 |
| 2450.00 | 23.0000 | .5861 | .84317 | 337.66 | .32606 | .0631 |
| 2450.00 | 22.0000 | .6177 | .85004 | 338.80 | .32698 | .0620 |
| 2450.00 | 21.0000 | .6523 | .85682 | 339.93 | .32793 | .0609 |
| 2450.00 | 20.0000 | .6903 | .86353 | 340.36 | .32891 | .0599 |
| 2450.00 | 19.0000 | .7322 | .87017 | 341.38 | .32992 | .0588 |
| 2450.00 | 18.0000 | .7787 | .87675 | 342.40 | .33098 | .0577 |
| 2450.00 | 17.0000 | .8306 | .88328 | 343.41 | .33208 | .0567 |
| 2450.00 | 16.0000 | .8891 | .88978 | 344.42 | .33323 | .0556 |
| 2450.00 | 15.0000 | .9552 | .89626 | 345.44 | .33444 | .0545 |
| 2450.00 | 14.0000 | 1.0309 | .90273 | 346.45 | .33572 | .0534 |
| 2450.00 | 13.0000 | 1.1181 | .90921 | 347.46 | .33707 | .0523 |
| 2450.00 | 12.0000 | 1.2200 | .91571 | 348.47 | .33851 | .0512 |
| 2450.00 | 11.0000 | 1.3404 | .92225 | 349.49 | .34005 | .0501 |
| 2450.00 | 10.0000 | 1.4849 | .92883 | 350.50 | .34172 | .0490 |
| 2450.00 | 9.0000 | 1.6617 | .93548 | 351.53 | .34354 | .0479 |
| 2450.00 | 8.0000 | 1.8829 | .94220 | 352.55 | .34554 | .0468 |
| 2450.00 | 7.0000 | 2.1674 | .94901 | 353.58 | .34778 | .0456 |
| 2450.00 | 6.0000 | 2.5470 | .95591 | 354.62 | .35033 | .0445 |
| 2450.00 | 5.0000 | 3.0789 | .96293 | 355.66 | .35331 | .0434 |
| 2450.00 | 4.0000 | 3.8771 | .97007 | 356.70 | .35689 | .0422 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| t | p | v^g | s | h^g | u^g | c_p^g |
|---------|---------|---------|--------|--------|--------|---------|
| 2450.00 | 3.0000 | 5.2082 | .97733 | 357.75 | .36144 | .0411 |
| 2450.00 | 2.0000 | 7.8715 | .98474 | 358.81 | .36775 | .0399 |
| 2450.00 | 1.0000 | 15.8638 | .99229 | 359.87 | .37335 | .0387 |
| 2450.00 | .8000 | 19.8603 | .99382 | 360.09 | .38174 | .0385 |
| 2450.00 | .6000 | 26.5213 | .99536 | 360.30 | .38609 | .0383 |
| 2450.00 | .4000 | 39.8435 | .99690 | 360.51 | .39220 | .0380 |
| 2450.00 | .2000 | 79.8107 | .99845 | 360.73 | .40261 | .0378 |
| 2475.00 | 34.0000 | .3658 | .77130 | 327.13 | .31787 | .0734 |
| 2475.00 | 33.0000 | .3802 | .77806 | 328.22 | .31858 | .0726 |
| 2475.00 | 32.0000 | .3956 | .78501 | 329.31 | .31931 | .0717 |
| 2475.00 | 31.0000 | .4120 | .79206 | 330.39 | .32006 | .0707 |
| 2475.00 | 30.0000 | .4295 | .79917 | 331.48 | .32082 | .0696 |
| 2475.00 | 29.0000 | .4483 | .80629 | 332.55 | .32159 | .0686 |
| 2475.00 | 28.0000 | .4684 | .81339 | 333.62 | .32238 | .0675 |
| 2475.00 | 27.0000 | .4900 | .82043 | 334.68 | .32318 | .0664 |
| 2475.00 | 26.0000 | .5131 | .82740 | 335.73 | .32401 | .0653 |
| 2475.00 | 25.0000 | .5381 | .83429 | 336.77 | .32485 | .0643 |
| 2475.00 | 24.0000 | .5651 | .84110 | 337.80 | .32571 | .0632 |
| 2475.00 | 23.0000 | .5944 | .84782 | 338.82 | .32660 | .0621 |
| 2475.00 | 22.0000 | .6262 | .85445 | 339.83 | .32751 | .0611 |
| 2475.00 | 21.0000 | .6611 | .86101 | 340.84 | .32845 | .0600 |
| 2475.00 | 20.0000 | .6994 | .86749 | 341.84 | .32942 | .0590 |
| 2475.00 | 19.0000 | .7416 | .87391 | 342.84 | .33042 | .0579 |
| 2475.00 | 18.0000 | .7886 | .88028 | 343.83 | .33147 | .0569 |
| 2475.00 | 17.0000 | .8409 | .88661 | 344.82 | .33256 | .0559 |
| 2475.00 | 16.0000 | .8998 | .89291 | 345.80 | .33370 | .0548 |
| 2475.00 | 15.0000 | .9666 | .89919 | 346.79 | .33490 | .0538 |
| 2475.00 | 14.0000 | 1.0429 | .90547 | 347.77 | .33617 | .0528 |
| 2475.00 | 13.0000 | 1.1309 | .91175 | 348.76 | .33751 | .0517 |
| 2475.00 | 12.0000 | 1.2336 | .91806 | 349.75 | .33894 | .0507 |
| 2475.00 | 11.0000 | 1.3550 | .92441 | 350.73 | .34048 | .0496 |
| 2475.00 | 10.0000 | 1.5009 | .93080 | 351.72 | .34214 | .0485 |
| 2475.00 | 9.0000 | 1.6792 | .93726 | 352.72 | .34395 | .0475 |
| 2475.00 | 8.0000 | 1.9022 | .94379 | 353.72 | .34594 | .0464 |
| 2475.00 | 7.0000 | 2.1892 | .95040 | 354.72 | .34817 | .0453 |
| 2475.00 | 6.0000 | 2.5721 | .95712 | 355.73 | .35071 | .0442 |
| 2475.00 | 5.0000 | 3.1086 | .96394 | 356.74 | .35368 | .0431 |
| 2475.00 | 4.0000 | 3.9137 | .97088 | 357.75 | .35725 | .0420 |
| 2475.00 | 3.0000 | 5.2562 | .97795 | 358.78 | .36179 | .0409 |
| 2475.00 | 2.0000 | 7.9425 | .98515 | 359.81 | .36809 | .0398 |
| 2475.00 | 1.0000 | 16.0034 | .99250 | 360.84 | .37869 | .0387 |
| 2475.00 | .8000 | 20.0342 | .99399 | 361.05 | .38207 | .0385 |
| 2475.00 | .6000 | 26.7525 | .99548 | 361.26 | .38642 | .0382 |
| 2475.00 | .4000 | 40.1892 | .99698 | 361.46 | .39252 | .0380 |
| 2475.00 | .2000 | 80.4998 | .99849 | 361.67 | .40293 | .0378 |
| 2500.00 | 34.0000 | .3723 | .77832 | 328.45 | .31849 | .0724 |
| 2500.00 | 33.0000 | .3868 | .78491 | 330.02 | .31919 | .0715 |
| 2500.00 | 32.0000 | .4023 | .79164 | 331.08 | .31992 | .0706 |
| 2500.00 | 31.0000 | .4189 | .79847 | 332.15 | .32065 | .0696 |
| 2500.00 | 30.0000 | .4365 | .80534 | 333.20 | .32140 | .0685 |
| 2500.00 | 29.0000 | .4554 | .81221 | 334.25 | .32217 | .0675 |
| 2500.00 | 28.0000 | .4757 | .81905 | 335.29 | .32295 | .0664 |
| 2500.00 | 27.0000 | .4974 | .82584 | 336.33 | .32374 | .0654 |
| 2500.00 | 26.0000 | .5207 | .83256 | 337.35 | .32456 | .0642 |
| 2500.00 | 25.0000 | .5459 | .83921 | 338.36 | .32539 | .0633 |
| 2500.00 | 24.0000 | .5731 | .84578 | 339.37 | .32624 | .0622 |
| 2500.00 | 23.0000 | .6026 | .85227 | 340.36 | .32712 | .0612 |
| 2500.00 | 22.0000 | .6347 | .85868 | 341.35 | .32802 | .0602 |
| 2500.00 | 21.0000 | .6698 | .86502 | 342.33 | .32895 | .0592 |
| 2500.00 | 20.0000 | .7084 | .87129 | 343.31 | .32991 | .0581 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| T | P | v^g | z | h^g | s^g | c_p^g |
|---------|---------|---------|--------|--------|--------|---------|
| 2500.00 | 19.0000 | .7510 | .87750 | 344.28 | .33091 | .0571 |
| 2500.00 | 18.0000 | .7983 | .88367 | 345.24 | .33195 | .0561 |
| 2500.00 | 17.0000 | .8512 | .88980 | 346.21 | .33303 | .0551 |
| 2500.00 | 16.0000 | .9106 | .89590 | 347.17 | .33417 | .0541 |
| 2500.00 | 15.0000 | .9779 | .90200 | 348.13 | .33536 | .0531 |
| 2500.00 | 14.0000 | 1.0548 | .90809 | 349.09 | .33661 | .0521 |
| 2500.00 | 13.0000 | 1.1436 | .91419 | 350.04 | .33795 | .0511 |
| 2500.00 | 12.0000 | 1.2472 | .92031 | 351.01 | .33937 | .0501 |
| 2500.00 | 11.0000 | 1.3696 | .92648 | 351.97 | .34090 | .0491 |
| 2500.00 | 10.0000 | 1.5167 | .93269 | 352.93 | .34255 | .0481 |
| 2500.00 | 9.0000 | 1.6966 | .93896 | 353.90 | .34435 | .0471 |
| 2500.00 | 8.0000 | 1.9215 | .94531 | 354.87 | .34633 | .0460 |
| 2500.00 | 7.0000 | 2.2110 | .95174 | 355.85 | .34856 | .0450 |
| 2500.00 | 6.0000 | 2.5972 | .95827 | 356.83 | .35109 | .0439 |
| 2500.00 | 5.0000 | 3.1382 | .96490 | 357.81 | .35404 | .0429 |
| 2500.00 | 4.0000 | 3.9502 | .97165 | 358.80 | .35760 | .0418 |
| 2500.00 | 3.0000 | 5.3042 | .97853 | 359.80 | .36213 | .0406 |
| 2500.00 | 2.0000 | 8.0133 | .98554 | 360.80 | .36842 | .0397 |
| 2500.00 | 1.0000 | 16.1429 | .99270 | 361.81 | .37901 | .0387 |
| 2500.00 | .8000 | 20.2061 | .99415 | 362.01 | .38240 | .0384 |
| 2500.00 | .6000 | 26.9836 | .99560 | 362.21 | .38674 | .0382 |
| 2500.00 | .4000 | 40.5348 | .99706 | 362.41 | .39285 | .0380 |
| 2500.00 | .2000 | 81.1888 | .99853 | 362.62 | .40325 | .0378 |
| 2525.00 | 34.0000 | .3787 | .78509 | 330.75 | .31909 | .0714 |
| 2525.00 | 33.0000 | .3933 | .79149 | 331.79 | .31979 | .0705 |
| 2525.00 | 32.0000 | .4090 | .79802 | 332.83 | .32051 | .0695 |
| 2525.00 | 31.0000 | .4256 | .80462 | 333.87 | .32123 | .0685 |
| 2525.00 | 30.0000 | .4435 | .81125 | 334.90 | .32198 | .0675 |
| 2525.00 | 29.0000 | .4625 | .81788 | 335.93 | .32273 | .0664 |
| 2525.00 | 28.0000 | .4829 | .82448 | 336.94 | .32350 | .0654 |
| 2525.00 | 27.0000 | .5047 | .83102 | 337.95 | .32429 | .0643 |
| 2525.00 | 26.0000 | .5282 | .83751 | 338.94 | .32509 | .0633 |
| 2525.00 | 25.0000 | .5536 | .84393 | 339.93 | .32592 | .0623 |
| 2525.00 | 24.0000 | .5810 | .85027 | 340.91 | .32676 | .0613 |
| 2525.00 | 23.0000 | .6107 | .85653 | 341.88 | .32763 | .0603 |
| 2525.00 | 22.0000 | .6431 | .86273 | 342.84 | .32852 | .0593 |
| 2525.00 | 21.0000 | .6785 | .86886 | 343.80 | .32945 | .0583 |
| 2525.00 | 20.0000 | .7174 | .87492 | 344.75 | .33040 | .0573 |
| 2525.00 | 19.0000 | .7603 | .88094 | 345.70 | .33139 | .0564 |
| 2525.00 | 18.0000 | .8080 | .88691 | 346.64 | .33242 | .0554 |
| 2525.00 | 17.0000 | .8613 | .89286 | 347.58 | .33349 | .0545 |
| 2525.00 | 16.0000 | .9212 | .89878 | 348.51 | .33462 | .0535 |
| 2525.00 | 15.0000 | .9891 | .90468 | 349.45 | .33580 | .0525 |
| 2525.00 | 14.0000 | 1.0666 | .91060 | 350.38 | .33705 | .0516 |
| 2525.00 | 13.0000 | 1.1562 | .91652 | 351.32 | .33838 | .0506 |
| 2525.00 | 12.0000 | 1.2606 | .92247 | 352.25 | .33979 | .0496 |
| 2525.00 | 11.0000 | 1.3842 | .92846 | 353.19 | .34131 | .0486 |
| 2525.00 | 10.0000 | 1.5325 | .93449 | 354.13 | .34295 | .0477 |
| 2525.00 | 9.0000 | 1.7139 | .94059 | 355.07 | .34474 | .0467 |
| 2525.00 | 8.0000 | 1.9408 | .94676 | 356.02 | .34672 | .0457 |
| 2525.00 | 7.0000 | 2.2327 | .95302 | 356.97 | .34893 | .0447 |
| 2525.00 | 6.0000 | 2.6221 | .95937 | 357.92 | .35146 | .0437 |
| 2525.00 | 5.0000 | 3.1677 | .96582 | 358.88 | .35440 | .0427 |
| 2525.00 | 4.0000 | 3.9866 | .97240 | 359.85 | .35796 | .0417 |
| 2525.00 | 3.0000 | 5.3521 | .97909 | 360.82 | .36248 | .0407 |
| 2525.00 | 2.0000 | 8.0841 | .98592 | 361.79 | .36876 | .0396 |
| 2525.00 | 1.0000 | 16.2824 | .99289 | 362.77 | .37934 | .0386 |
| 2525.00 | .8000 | 20.3819 | .99430 | 362.97 | .38272 | .0384 |
| 2525.00 | .6000 | 27.2146 | .99571 | 363.17 | .38706 | .0382 |
| 2525.00 | .4000 | 40.8803 | .99714 | 363.36 | .39317 | .0380 |

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

| t | p | v^g | z | A^g | z^g | c_p^g |
|---------|---------|---------|--------|--------|--------|---------|
| 2525.00 | .2000 | 81.8777 | .49857 | 363.56 | .40357 | .0378 |
| 2550.00 | 34.0000 | .3850 | .79161 | 352.52 | .31968 | .0703 |
| 2550.00 | 33.0000 | .3998 | .79782 | 333.54 | .32037 | .0694 |
| 2550.00 | 32.0000 | .4156 | .80414 | 334.56 | .32108 | .0684 |
| 2550.00 | 31.0000 | .4324 | .81052 | 335.57 | .32180 | .0674 |
| 2550.00 | 30.0000 | .4503 | .81692 | 336.58 | .32253 | .0664 |
| 2550.00 | 29.0000 | .4695 | .82331 | 337.57 | .32328 | .0654 |
| 2550.00 | 28.0000 | .4900 | .82968 | 338.56 | .32404 | .0644 |
| 2550.00 | 27.0000 | .5120 | .83599 | 339.54 | .32482 | .0634 |
| 2550.00 | 26.0000 | .5357 | .84225 | 340.52 | .32562 | .0624 |
| 2550.00 | 25.0000 | .5612 | .84844 | 341.48 | .32643 | .0614 |
| 2550.00 | 24.0000 | .5888 | .85457 | 342.43 | .32727 | .0604 |
| 2550.00 | 23.0000 | .6188 | .86062 | 343.38 | .32813 | .0594 |
| 2550.00 | 22.0000 | .6514 | .86661 | 344.32 | .32901 | .0585 |
| 2550.00 | 21.0000 | .6871 | .87254 | 345.25 | .32993 | .0575 |
| 2550.00 | 20.0000 | .7263 | .87841 | 346.17 | .33087 | .0566 |
| 2550.00 | 19.0000 | .7696 | .88424 | 347.10 | .33186 | .0556 |
| 2550.00 | 18.0000 | .8177 | .89003 | 348.01 | .33288 | .0547 |
| 2550.00 | 17.0000 | .8714 | .89579 | 348.93 | .33394 | .0538 |
| 2550.00 | 16.0000 | .9318 | .90153 | 349.84 | .33506 | .0529 |
| 2550.00 | 15.0000 | 1.0002 | .90726 | 350.75 | .33624 | .0519 |
| 2550.00 | 14.0000 | 1.0784 | .91300 | 351.66 | .33748 | .0510 |
| 2550.00 | 13.0000 | 1.1687 | .91875 | 352.57 | .33880 | .0501 |
| 2550.00 | 12.0000 | 1.2740 | .92453 | 353.49 | .34020 | .0491 |
| 2550.00 | 11.0000 | 1.3986 | .93035 | 354.40 | .34171 | .0482 |
| 2550.00 | 10.0000 | 1.5482 | .93622 | 355.32 | .34334 | .0473 |
| 2550.00 | 9.0000 | 1.7311 | .94215 | 356.23 | .34513 | .0463 |
| 2550.00 | 8.0000 | 1.9599 | .94816 | 357.16 | .34710 | .0454 |
| 2550.00 | 7.0000 | 2.2543 | .95424 | 358.08 | .34930 | .0444 |
| 2550.00 | 6.0000 | 2.6470 | .96042 | 359.01 | .35182 | .0435 |
| 2550.00 | 5.0000 | 3.1972 | .96671 | 359.95 | .35476 | .0425 |
| 2550.00 | 4.0000 | 4.0229 | .97311 | 360.89 | .35830 | .0415 |
| 2550.00 | 3.0000 | 5.3998 | .97963 | 361.83 | .36281 | .0406 |
| 2550.00 | 2.0000 | 8.1548 | .98628 | 362.78 | .36909 | .0396 |
| 2550.00 | 1.0000 | 16.4218 | .99307 | 363.74 | .37966 | .0386 |
| 2550.00 | .8000 | 20.5556 | .99444 | 363.93 | .38304 | .0384 |
| 2550.00 | .6000 | 27.4456 | .99582 | 364.12 | .38738 | .0382 |
| 2550.00 | .4000 | 41.2257 | .99721 | 364.32 | .39348 | .0380 |
| 2550.00 | .2000 | 82.5665 | .99860 | 364.51 | .40389 | .0378 |

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| 13 ABSTRACT <p>The experimental program at this Laboratory to measure various thermo-physical properties of sodium, potassium, and cesium has been completed. Final reports on two of the alkali metals, sodium and potassium, have been published; and this is the final reporting on cesium. Experimental results are presented for the density and vapor pressure of the liquid and for various saturation and superheat properties of the vapor. A virial equation of state is advanced and is used thermodynamically to derive additional properties of the vapor. For example, enthalpy, entropy, specific volume, and specific heat are tabulated for some 1100 selected vapor states in the temperature range from 1250° to 2550°F and in the pressure range from 0.2 to 34.0 atm.</p> | | |

Security Classification

| 14. KEY WORDS | | LINK A | | LINK B | | LINK C | |
|---|--|--------|----|--------|----|--------|----|
| | | ROLE | WT | ROLE | WT | ROLE | WT |
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